Contract NAS8-28144
DPD No. 282
DR No. MA-04

Volume I

Final Report

September 1972

Executive Summary

Astronomy Sortie Missions Definition Study

(NASA-CR-124042) ASTRONOMY SORTIE MISSIONS DEFINITION STUDY. VOLUME 1: EXECUTIVE SUMMARY Final Report (Martin Marietta Corp.) 70 p HC $5.50 CSCL 03A

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Contract NAS8-28144
DPD No. 282
DR No. MA-04

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ASTRONOMY SORTIE MISSION DEFINITION STUDY

EXECUTIVE SUMMARY

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FOREWORD

This document is submitted in accordance with the Data Procurement Document Number 282, Data Requirement Number MA-04 under the George C. Marshall Space Flight Center Contract NAS8-28144.

This is the first of four volumes of the Astronomy Sortie Missions Definition Study Final Report. This volume is the Executive Summary and it summarizes the significant achievements and activities of the study effort.

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PREFACE

The final report of this study is contained in four volumes, of which this is Volume I. They are:

Volume I - Astronomy Sortie Missions Definition Study Final Report: Executive Summary - This volume summarizes the significant achievements and activities of the study effort.

Volume II - Astronomy Sortie Missions Definition Study Final Report:

Book 1 - Astronomy Sortie Program Technical Report - Book 1 of this volume includes the definition of telescope requirements, preliminary mission and systems definition, identification of alternative sortie programs, definition of alternative sortie programs, the evaluation of the alternative sortie programs and the selection of the recommended Astronomy Sortie mission program. This volume identifies the various concepts approached and documents the rationale for the concept and approaches selected for further consideration.

Book 2 - Appendix - Book 2 of this volume contains the Baseline Experiment Definition Documents (BEDDs) that were prepared for each of the experiments considered during the study.

Volume III - Astronomy Sortie Missions Definition Study Final Report:

Book 1 - Design Analyses and Trade Studies - Book 1 of this volume includes the results of the design analyses and trade studies conducted on candidate concepts during the selection of recommended configurations as well as the design analyses and trade studies conducted on the selected concept.

Book 2 - Appendix - Book 2 of this volume contains the backup or supporting data for the design analyses and trade studies that are summarized in Volume III, Book 1.

Volume IV - Astronomy Sortie Missions Definition Study Final Report:

Program Development Requirements - This volume contains the planning data for subsequent phases and includes the gross project planning requirements; schedule, milestones and network; and supporting research and technology.

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I. INTRODUCTION

The realization of a fully operational Space Shuttle will open the door for unparalleled research opportunities in space astronomy. One mode of operation envisioned for the Space Shuttle is the short-duration sortie mission. The sortie mission would consist of a low earth orbit of approximately seven-days duration during which time research would be conducted by an on-orbit experiment crew using a scientific payload located in the Space Shuttle cargo bay.

For research in astronomy, the Space Shuttle sortie mission offers significant scientific advantages over ground-based observatories and operational advantages over present day automated satellites. Several of the more important scientific advantages are: (1) the ability to escape the earth's atmosphere and, therefore, open up the entire electromagnetic spectrum to research; (2) the elimination of atmospheric pertubrations and, thus, the capability to utilize the spatial resolution of the telescopes that are currently limited to approximately 1/2 $\widehat{\text{sec}}$ for ground-based observatories; and (3) the capability to continually observe the sun for days without obscurations by the earth. Combining these scientific advantages with the Space Shuttle operational advantages, such as (1) the large payload capability; (2) the low cost operations; (3) the frequent flight opportunities; (4) the capability to return the experiment to earth for refurbishment and retrofit; and (5) the availability of the experiment observer on-orbit with the experiment, offers the scientific community a unique capability for further research in the field of astronomy.

It is important to note that as the Astronomy Sortie mission payloads are developed, they will become facilities that will parallel the operations of ground based observatories. The Astronomy Sortie mission facilities will be capable of being reused many times by a number of different observers. The basic optics and detectors will be available for use by all qualified observers and time on the facility will be scheduled much like present day observatories.

While the opportunities for advancements in space astronomy exist with the sortie mission concept, it is evident that significant planning is required by NASA to ensure an orderly and timely Astronomy Sortie mission program. The program defined for the sortie missions must be cognizant of the overall astronomy program objectives and the capabilities, balloon-launched payloads, sounding rocket programs, and automated satellites. Each of these programs has unique characteristics and capabilities that must be considered when defining the astronomy objectives for the sortie missions. NASA is currently defining the scientific objectives for the Astronomy Sortie missions through studies and in-house working groups. After the scientific objectives are defined, the next step will be to define the instruments that satisfy the objectives. Once the objectives and instruments are defined, the next steps in the evolution of the Astronomy Sortie mission program will be the definition of support hardware, interface analyses on the Shuttle and Sortie Lab, operational requirements, and mission analyses.

The objectives of this study were to determine if a group of existing astronomy experiments, with stated scientific objectives, could be accommodated by the sortie mission, what the operational concept would be, what support hardware would be required, what kind of interfaces would be required with the Space Shuttle and Sortie Lab, and what the mission profiles would be.

The results of the study indicate that the Astronomy Sortie mission concept: (1) is technically feasible using present-day technology with a few exceptions; (2) is responsive to the stated scientific objectives; and (3) does provide an important contribution to the overall space astronomy program.

II. STUDY OBJECTIVES

The purpose of this study was to provide NASA with an overview of the requirements for an Astronomy Sortie mission program that would be operated in conjunction with an operational Space Shuttle. The specific objectives of the study are identified below.

1. *Development conceptual designs and interfaces for sortie missions including telescopes, mounts, controls, displays and other support equipment that are to be mounted on a Government-supplied sortie carrier.* The Government-supplied sortie carrier was the Sortie Lab and pallet. The interface definition included the Space Shuttle, Sortie Lab, and pallet interfaces, as well as the interfaces on the astronomy telescopes and support hardware. The conceptual design was for that hardware peculiar to the Astronomy Sortie missions and did not include the design of equipment or hardware that was a basic part of the Sortie Lab, pallet, or Space Shuttle.

2. *Evaluate the responsiveness of the sortie mission concept to stated scientific objectives.* A group of solar and stellar telescopes, with stated scientific objectives, were baselined for the study. The objective was to determine how well the sortie mission satisfied these scientific objectives.

3. *Identify and define the on-orbit manned operational techniques and all related mission hardware that would be required to complete the Shuttle sortie mission in astronomy.* The objective was to determine what activities should be performed by the on-orbit experiment observer and the support equipment that would be required to provide the observer with the capability.

4. *Develop a system concept encompassing the sortie mission from mission planning through postflight engineering and scientific documentation.* The objective was to develop a mission scenario that included all phases of the sortie mission, to identify those functions that would be performed during each mission phase, and to identify the resources and support hardware that would be required to satisfy each function.

5. *The Astronomy Sortie mission objectives shall be resolved into appropriate engineering requirements; i.e., thermal control system, pointing control system, data handling system, etc.* The objective was to define the interface requirements for the Astronomy Sortie payloads to ensure that the supporting systems (i.e., Shuttle, Sortie Lab, pallet, etc) have adequate capabilities, or that supporting hardware had been identified to supplement the capabilities that existed on the supporting systems.

6. *Provide development schedules and supporting research and technology requirements for Shuttle sortie hardware.* The objective was to provide planning data for use by NASA.

III. RELATIONSHIP TO OTHER NASA EFFORTS

In the performance of this study it was advantageous to use the results of previous and on-going NASA efforts in the areas of Space Shuttle, Sortie Lab, pallet and experiment definitions, and management and operational philosophies. Each of these areas had an impact on the study results; the relationship of these NASA efforts to this study are identified in this chapter.

A. SPACE SHUTTLE

The definition of the Space Shuttle interface and operational capabilities and constraints were of primary importance to the Astronomy Sortie mission definition because the Shuttle provides the transportation to and from orbit as well as the base for experiment operations while on-orbit. The design of the astronomy experiments and support hardware was dependent on the Shuttle in terms of the cargo bay environments, the inertial attitude constraints, the stabilization capabilities, the center-of-gravity (cg) constraints, the payload capabilities, the communications capabilities, the size and type of experiment crew available, the length of the Sortie mission, etc. The operational concept defined for the Astronomy Sortie missions was dependent on the Shuttle in terms of the turnaround time, the time available for installation and verification of payloads, the time available for installing expendables, etc. In summary, the capabilities and constraints of the operational Space Shuttle were fundamental to the definition of the Astronomy Sortie mission program. Consequently, this study did use the results of the Phase B Space Shuttle studies (Ref 1,2) and the SOAR study (Ref 3) in defining the Space Shuttle capabilities and constraints. In addition, the RFP for the Space Shuttle Program (Ref 4) and the results of in-house efforts in response to this RFP were also used in this study to maintain the latest definition of the Space Shuttle.

B. SORTIE LAB AND PALLET

The definition of the Sortie Lab and pallet was also of primary importance to this study. The Sortie Lab provides the basic subsystem support to the astronomy payload and the pressurized volume for the operation of the astronomy payload by the experiment crew. The pallet provides the standard strongback for attachment of experiments and support equipment in the nonpressurized area of the Shuttle cargo bay. The capabilities and constraints of these two interfacing elements dictate the peculiar support hardware that is required for the Astronomy Sortie missions. The Sortie Lab and pallet definition used for this study was the MSFC document, *Sortie Can Conceptual Design* (Ref 5). In addition to this document, the results of the Phase B RAM study (Ref 6) and the SOAR study (Ref 3) were also used to supplement the information available from the MSFC study.

C. EXPERIMENT DEFINITION

The telescopes and arrays used as a baseline for this study are representative of the class of instruments that might be flown on a sortie mission. It was not the intent of this study to define the Astronomy Sortie mission objectives or the instruments that should be flown on the sortie missions, but rather to take some representative instruments and use these as a baseline to determine the sortie mission feasibility, the major interfaces between the instruments and the Space Shuttle and Sortie Lab, and the integration requirements. A number of existing NASA documents were used for the baseline experiment definition, but the NASA Blue Book (Ref 7) and the results of the Orbital Astronomy Support Facility study (Ref 8) received the most emphasis. In addition to the existing documentation, this study did receive valuable information and guidance from personnel at NASA/AMES on the IR telescope; personnel at NASA/MSFC on the Stratoscope III and photoheliograph telescopes; Dr Earle Mayfield of the Aerospace Corporation on the results of the study *Scientific Objectives and Instrument Performance Criteria for a Large Solar Observatory* (Ref 9); Dr. A Keith Pierce of the Kitt Peak National Observatory on the operation of the Kitt Peak observatories; and personnel from NASA/Headquarters on the goals and objectives of the astronomy instruments for a Space Shuttle sortie mission.

D. MANAGEMENT AND OPERATIONAL PHILOSOPHIES

The management and operational philosophis defined for the Astronomy Sortie mission program are derived, in part, from other NASA studies. The results of the studies *Implementation of Research and Application Modules at the Shuttle Launch Site* (Ref 10) and *Scientific Objectives and Instrument Performance Criteria for a Large Solar Observatory* (Ref 9) were very instrumental in the definition of the overall operational concept for the Astronomy sortie mission program.

IV. METHOD OF APPROACH AND PRINCIPAL ASSUMPTIONS

A basic systems engineering approach was used in the performance of this study and the principal assumptions were the ground rules and guidelines provided by the NASA/MSFC, Contracting Officer's Representative (COR).

A. METHOD OF APPROACH

The systems approach used in the study consisted of: (1) defining the objectives; (2) determining the system requirements from the objectives; (3) evaluating the alternatives that satisfy the requirements; (4) selecting one alternative for further analysis; (5) conducting a preliminary design for the selected alternative; and (6) developing the planning data for the overall Astronomy Sortie program.

1. Objectives

Two types of objectives were defined for the study: (1) study objectives contained in the contract statement-of-work; and (2) objectives of the astronomy experiments and the sortie mode of operation. The statement-of-work objectives provided the basic structure for the study, while the experiment and sortie mode objectives were the objectives that had to be satisfied by the preliminary design.

2. Requirements

The operational and accommodation requirements and constraints were determined for each of the astronomy experiments provided as a baseline for the study. The requirements and constraints were determined by reviewing the existing documentation for the experiments, resolving the inconsistencies, and modifying the experiment definitions, as required, to make them more compatible with the sortie mode of operation.

3. Alternatives

The next step in the study was to perform conceptual designs and preliminary mission and systems analyses on the alternatives that satisfied the requirements and constraints. The conceptual designs and preliminary analyses were to a depth that allowed an evaluation of the alternatives, and were the basis for selecting one alternative for further analysis.

4. Preliminary Design

A preliminary design was conducted on the selected alternative to a depth sufficient to demonstrate the feasibility of the Astronomy Sortie mission program and to allow the development of the schedules and funding levels that would be required for the program. The preliminary design included the operational, mission, systems, and subsystems concepts, as well as the definition of the requirements on the interfacing elements.

5. Planning Data

The last step in the approach was the development of the planning data for the overall Astronomy Sortie program. This planning data included development schedules, and SRT requirements.

B. PRINCIPAL ASSUMPTIONS

The principal assumptions for the study were provided by the NASA/MSFC, COR as a part of the contract statement-of-work. The principal assumptions are:

1) The baseline astronomy experiments consisted of a set of intermediate class solar and stellar telescopes and a group of high-energy arrays. These experiments were considered representative of the class of instruments that might be flown on the sortie mission.

2) The maximum flight schedule for the Astronomy Sortie program identified two flights per year in 1979, grew to a maximum of eight flights per year in 1983, and continued at this rate through 1990.

3) Each sortie payload consisted of a primary telescope and secondary group of high-energy arrays or solar telescopes.

4) The operational concept for the sortie mission was seven days duration with two scientific crewmen available for 24-hr/day operation of the experiments.

5) The carrier for the astronomy experiments was the Sortie Lab and pallet defined by NASA/MSFC.

6) The study was to make maximum use of previous or on-going NASA studies.

B

V. BASIC DATA GENERATED AND SIGNIFICANT RESULTS

The general results of this study are that the Astronomy Sortie mission concept presented is feasible, using state-of-the-art hardware with a few exceptions, and that the sortie mode of operation does offer some distinct advantages to the overall astronomy program.

The specific areas that are reported on in this final report are: (1) experiment definition; (2) alternative concepts that were considered; (3) mission and systems analyses; (4) subsystem definition; (5) interfaces; and (6) program development requirements.

The on-orbit configuration concept for the solar and stellar payloads is shown in Fig. 1. The solar payload consists of the entire complement of solar telescopes, while the stellar payloads are made up of one stellar telescope and a group of high-energy arrays. The configurations shown are based on the Shuttle maintaining an inertial attitude where the longitudinal axis (X) is perpendicular to the orbit plane (X-POP). For the solar payload, a beta angle of near 1.57 radians (90 deg) is required to provide continuous sun during the seven-day mission. With the X-POP inertial attitude and the beta angle constraint it is necessary to rotate the solar payload 1.57 radians (90 deg) to enable simultaneous viewing of the sun with both experiment packages. The stellar payloads do not require deployment of the entire payload because they can view a hemisphere in the configuration shown. The concepts shown in Fig. 1 are the recommended configurations for the Astronomy Sortie missions and the information contained in this report is based on these concepts.

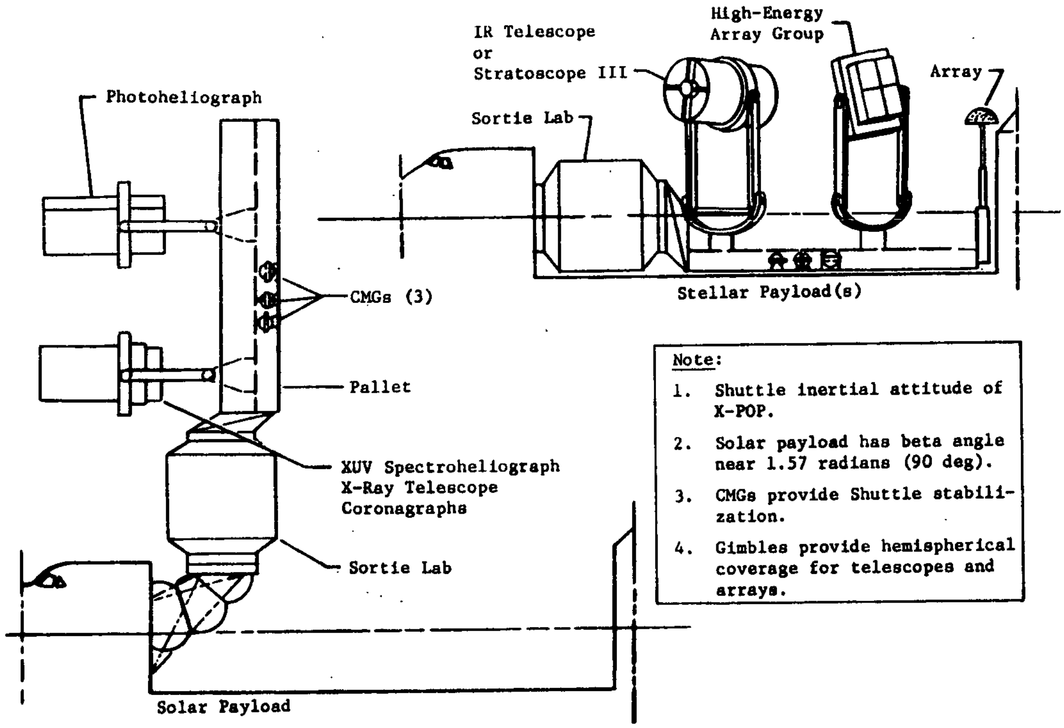


Fig. 1 Payload Configuration Concepts

A. EXPERIMENT DEFINITION

The experiments provided as a baseline for the study were a group of intermediate size telescopes and a group of high-energy arrays. These experiments were considered representative of the class of instruments that might be flown on the Astronomy Sortie missions. Tables 1 and 2 summarize the performance and physical characteristics of the telescopes and arrays.

The results of the experiment definition phase of this study were that all but one of the stated scientific objectives can be satisfied with the sortie mode of operation and that the telescopes and arrays can be configured to be compatible with the sortie mode. The scientific objective that was eliminated for the sortie mode of operation was the IR telescope sky survey. This survey would require approximately one year of on-orbit operation to perform. The primary changes that were made to the telescope definitions were the use of film for the recording device and the repackaging of the telescopes to make them more compatible with the sortie mode of operation.

Table 1 Telescope Summary

Parameter \ Telescope	Solar					Stellar	
	Photoheliograph	Spectroheliograph	X-Ray	Inner Coronagraph	Outer Coronagraph	Stratoscope III	IR
Type	Gregorian	Prime Focus	Grazing Incidence	Refractor	Refractor	Ritchey-Chretian	Cassegrain
Aperture, cm	100	25	32	2.45	4.0	120	100
f/number, overall	50	12	10	12.9	2.25	12	10
Wavelength Range, angstroms	2000 to 7000	170 to 650	2 to 100	4000 to 7000	4000 to 7000	900 to 20,000	0.7 to 1000 microns
Wavelength Specification, angstroms	6328	170	100	6328	6328	6328	4 microns
Field of View, min	3.0	32.0	10.0	195	900	6	5
Angular Resolution, sec	0.3	1.2	1.0	14	20	0.3	4.0
Pointing, sec	0.3	15	20	2	2	0.3	4
Guiding Error, sec	0.03	0.1	0.1	1	1	0.02	0.4
Size, m (ft)	4.6x1.9x1.4 (15.1x6.3x4.7)	3.4x1.3x0.76 (11.3x4.4x2.5)	4.6x0.7 dia (15x2.3 dia)	3.8x1.2x0.7 (12.5x3.9x2.1)		4.2x1.9 dia (13.8x6.2 dia)	3.6x2.1 dia (12x7 dia)
Weight, kg (lb)	1000 (2200)	430 (954)	392 (862)	430 (954)		1800 (4000)	1988 (4383)

Table 2 Array Summary

Parameter \ Array	X-Ray					Gamma-Ray	
	Wide Coverage X-Ray Detector	Large Area X-Ray Detector	Large Modulation Collimator	Collinated Plane Crystal Spectrometer	Narrow Band Spectrometer Polarimeter	Gamma-Ray Spectrometer	Low Background Detector
Energy Band, kev	2 to 100	0.1 to 100	0.1 to 100	0.5 to 10	5.94 to 8.37	60 to 10,000	300 to 10,000
Field of View, deg	180	1.15	2.87	30	1.0	72	110
Pointing Accuracy, min	--	6.8	3.4	1.0	5.0	69.0	60.0
Pointing Stability, min	31.0	6.8	scans	1.0	1.0	10.2	30.0
Size, m (ft)	1.2x2.0 dia (3.9x6.6 dia)	6 modules @ 1.2x0.6x0.5 3.9x2x1.6)	6 modules @ 1.2x0.6x0.85 (3.9x2x2.8)	3 modules @ 1.33x1.22x0.61 (4.4x4x2)	9 modules @ 0.6x0.75 dia (2x2.5 dia)	0.7x0.34x0.34 (2.3x1.1x1.1)	1.6x1.6x0.75 (5.2x5.2x2.5)
Weight, kg (lb)	250 (550)	315 (695)	375 (826)	261 (574)	543 (1197)	155 (341)	910 (2000)

Film was used because it is a high resolution state-of-the-art recording device and because it is a high density storage medium. For a seven-day mission, the film cassettes can be sized to last the entire mission without resupply. Film will also minimize the downlink telemetry requirements since the majority of the data will be stored on board.

The repackaging of several telescopes was necessary to fit them into the common mount and the Shuttle cargo bay. For the Astronomy Sortie concept defined in this report, the astronomy telescopes should not exceed 2.13 m (84 in.) in diameter and approximately 4.6 m (15 ft) in length.

In the performance of the experiment definitions it was assumed that the telescope reference document values of aperture, focal ratio, and field of view were accurate representations of the scientist's requirements. Other parameters, such as obscuration, pointing, and guiding were examined and modified according to best engineering judgment. This judgment was based on past experience or first order calculations for such factors as format, plate scale, obscuration, and wavefront error. Modulation transfer function (MTF) analysis was used to establish the allowable guide errors and expected angular resolutions.

In the array definitions the major changes were to the array area and the wavelength range. Both of these changes resulted in array definitions with greater capabilities than those provided in the reference documentation.

1. <u>Photoheliograph</u>

The photoheliograph (PHG) will provide man's most detailed observation of solar features until the Large Solar Observatory (LSO) becomes operational. The PHG will be supplied with a variety of cameras and spectrometers to suit most observational programs and it will be possible to tailor the instruments for a particular type of observation for a specific sortie mission. The PHG defined for this study is a derivative of the 65-cm PHG defined by the Ball Brothers Research Corporation (Ref 11). Some rearrangement of component parts was feasible for the sortie mode of operation and a dual-range spectrograph was added to the instrument complement.

2. XUV Spectroheliograph

The spectroheliograph (SHG) is an extreme ultraviolet instrument operated essentially as a slitless spectrograph. It records a monochromatic image of the sun in each emission line. The SHG baselined for this study is basically the same instrument defined by the OASF study (Ref 8). The expected resolution of the instrument was modified based on the results of the MTF analysis.

3. X-Ray Telescope

The X-ray telescope (XRT) will observe solar phenomena with high spatial, spectral and temporal resolution. The XRT baselined for this study is a derivative of the XRT defined by the Blue Book (Ref 7). To accommodate the XRT on the sortie mission it was necessary to reduce the overall length of the telescope from 7.15 m (23.5 ft) to 4.6 m (15 ft). It was assumed that the grazing angles identified in the Blue Book satisfied the scientific objectives and that it was desirable to maintain these angles. Consequently, the aperture of the XRT was reduced from 50 cm to 32 cm to maintain the grazing angles.

4. Coronagraphs

The coronagraphs are essentially white light instruments that are operated as patrol cameras. The inner coronagraph (IC) views to six solar radii and the outer coronagraph (OC) to 30. The coronagraphs are based on the Blue Book (Ref 7) and OASF (Ref 8) concepts with a few exceptions. The Blue Book version had two mirrors in the optical path of the IC to shorten the instrument. Because these mirrors can only degrade performance by extra scattering and wavefront error, the fold was eliminated for the sortie mission baseline and the length of the IC was adjusted accordingly. In addition, the spectral coverage was reduced from the 4000 to 10,000 Angstroms range identified in the reference documentation to 4000 to 7000 Angstroms. This reduction in spectral coverage eliminated the need for infrared-sensitive film which has moderate to low resolving power.

5. Stratoscope III

The Stratoscope III (SIII) will provide a broad range of scientific instruments for stellar observations. It will be a successor to the balloonborne SIII and a predecessor to the Large Space Telescope (LST). The SIII baselined for this study is a scaled-down version of Itek's 3-m concept proposed for LST. Although this version of the SIII does not correspond to the SIII concept being defined by NASA/MSFC, it is representative of the class of instrument that will fly on the sortie missions.

6. IR Telescope

The IR telescope (IRT) will give astronomers their first long term, high resolution view of the universe in the wavelengths between 1 and 1000 μm. The entire telescope will be cooled to 28°K or below and the detectors will be cooled to approximately 2°K. The IRT baselined for the study is derived from the Blue Book (Ref 7). This telescope was selected for a detailed analysis of the structural and cryogenic systems and the results of these analyses are summarized in the subsystems section of this report.

7. High-Energy Arrays

The X-ray and gamma-ray arrays baselined for this study are derivatives of the Blue Book definitions (Ref 7). The primary differences between the arrays baselined for the sortie missions and the Blue Book definitions were that the baselined arrays were repackaged to provide increased detector viewing area and the detectors were modified to provide a wider spectral coverage.

B. ALTERNATIVES CONSIDERED

The payload accommodation concept selected for the Astronomy Sortie mission is shown in Fig. 2. The salient features of this concept are the standard Sortie Lab and pallet, the deployment yoke, the azimuth yoke and table, the telescope gimbal assembly, the control moment gyro (CMG) assembly, and the array platform assembly. The Sortie Lab provides the pressurized volume that houses the experiment crew during the experiment operations and it also provides the subsystem support to the experiments and experiment support hardware. The pallet provides the strongback for mounting the experiments and experiment support hardware. The deployment yoke rotates through 1.57 radians (90 deg) and deploys the telescopes and arrays out of the pallet, providing clear access for viewing a hemisphere. The azimuth yoke and table, in conjunction with the elevation drive on the telescope gimbal assembly and the array platform assembly, provide the telescopes and arrays with hemispherical coverage of the celestial sphere. The CMG assembly provides the Shuttle stabilization during the seven-day sortie mission. The telescope gimbal assembly provides the mounting interface for the telescopes and the precision fine pointing and stabilization. The array platform assembly provides the mounting interface for the high-energy array groups.

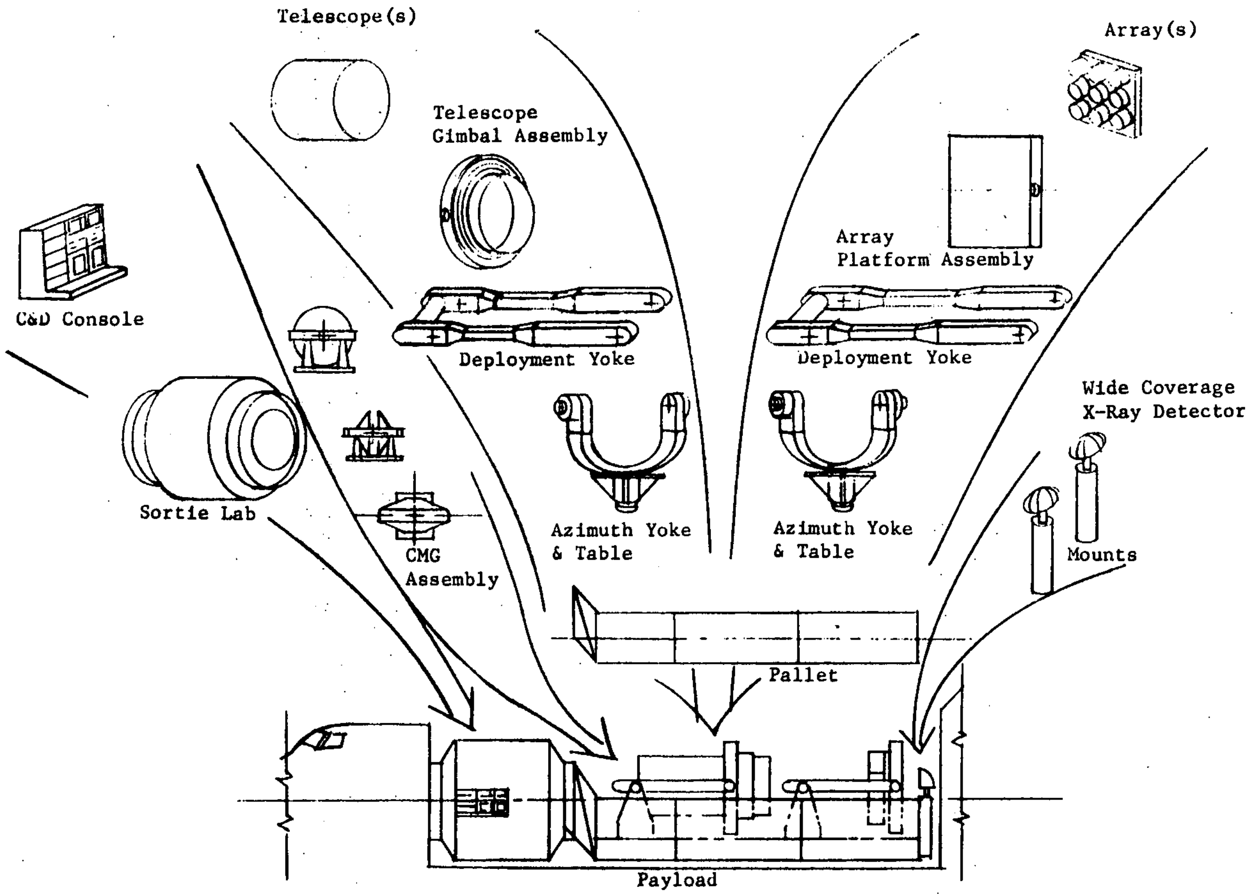


Fig. 2 Payload Accommodation Concept

Several alternative concepts were investigated and discarded during the study. The alternatives included: (1) the use of the Space Shuttle for the pressurized volume in place of the Sortie Lab; (2) the use of a common environmental shroud that enclosed the equipment located on the pallet; (3) the use of the Shuttle for pointing the experiments instead of the azimuth and elevation gimbal; and (4) the penetration of the Sortie Lab with the IR telescope to enable on-orbit shirt sleeve access to the telescope focal point.

1. <u>Shuttle Pressurized Volume</u>

The Sortie Lab was selected as the preferred means for providing the pressurized volume for experiment operation because this approach: (1) minimizes the interfaces between the astronomy experiments and the Space Shuttle; (2) provides for the separation of experiment crew operations from the Shuttle crew activities; (3) simplifies the Shuttle integration activities; and (4) provides the maximum flexibility and growth to the astronomy program.

Although the use of the Sortie Lab does result in a weight penalty of approximately 1815 kg (4000 lb) and a reduction of 4.6 m (15 ft) of available cargo bay length, the advantages of the standard Sortie Lab override the disadvantages. The standard Sortie Lab concept allows the experiments and the experiment support hardware to be integrated and checked out before installation in the Shuttle cargo bay. The Sortie Lab will have standard interfaces with the Shuttle that will simplify the Shuttle integration tasks and enable fast turnaround. The pressurized volume available in the Sortie Lab will provide flexibility and growth for the astronomy program since it will be possible to add additional instruments that could be operated through the airlock that exists with the Sortie Lab. Finally, because the Sortie Lab is envisioned as a piece of standard hardware, the astronomy program would not be required to develop the subsystem support hardware required for the operation of the experiments (i.e., power, data, thermal, etc). This should result in substantial cost savings over the life of the 12-year astronomy program.

2. Overall Environmental Shroud

Two approaches to providing environmental protection to the astronomy experiments were investigated during the study. One concept was the use of an overall environmental shroud that enclosed the entire Shuttle cargo bay aft of the Sortie Lab. The other concept was the use of localized protection for each of the experiments. The overall shroud approach only provides environmental protection during the ascent and descent phases of the mission since the experiments must view space during operation. The selected approach for the Astronomy Sortie mission program was the use of localized protection for the astronomy experiments. This selection was based on the thermal and acoustical environment that the telescope would see during the ascent phase of the mission.

The thermal analysis indicated that the internal temperatures of the telescopes would experience small variations during the ascent phase of the mission. Typical variations were an increase of 0.7°F for an insulation conductance of 0.02 Btu/ft^2-hr-°F and 3.0°F for a conductance of 0.1 Btu/ft^2-hr-°F. These temperature changes were for an initial launch temperature of 0°F. The first insulation conductance (0.02), is typical of a good insulation and is the conductance value for the Multiple Docking Adapter (MDA) on Skylab. The second value (0.1) would be the conductance for an insulation with five times the number of penetrations that exist on the MDA. Since the telescopes will require thermal protection equivalent to the above values during the on-orbit operations, the overall environmental shroud is not required for thermal purposes.

During the analysis of the acoustical environment in the Shuttle, an overall sound pressure level (OASPL) of 155 dB was used for the cargo bay. It was assumed that the telescopes could survive an OASPL of 140 dB and Titan III test data were used to determine the density of attenuation material that would be required to lower the OASPL from 155 dB to 140 dB. The results of this analysis indicated that 9.76 kg/m^2 (2.0 lb/ft^2) of material would lower the OASPL to the required 140 dB. Calculated wall densities for the telescopes ranged from a minimum of 9.78 kg/m^2 (2.04 lb/ft^2) to a maximum of 66.3 kg/m^2 (13.6 lb/ft^2). In addition, the Shuttle RFP (Ref 4) specified a maximum OASPL in the cargo bay of 145 dB. Although the tolerances have not been identified for the astronomy experiments, the lower OASPL specified in the Shuttle RFP and the telescope wall densities indicate that the acoustic environments would cause only localized problems on extremely delicate instruments.

Based on the results of the thermal and acoustical analyses, it was recommended that local environmental protection should be adopted for the astronomy experiments.

3. Shuttle Pointing of Experiments

The use of the Shuttle to point the experiments, instead of the azimuth and elevation gimbals, was investigated and discarded. The primary reasons for selecting the azimuth and elevation gimbals for the experiment pointing technique were: (1) hemispherical coverage is available without maneuvering the Shuttle; (2) an inertial orientation of the Shuttle longitudinal axis perpendicular to the orbit plane (X-POP) is possible; (3) a fast slew rate is possible; and (4) the telescopes can be pointed independent of the arrays.

To point the experiments with the Shuttle would require maneuvering the Shuttle each time a new target is desired. This is expensive in terms of CMGs, propellants, or time. To maneuver the Shuttle about its Y or Z axes at a rate of 0.1 rad/min (6 deg/min) would require a momentum of 1.43×10^4 N-m-s (1.06×10^4 ft-lb-sec) for a CMG system and 3.35×10^4 N-m-s (2.48×10^4 ft-lb-sec) for a propulsive system. To provide a CMG system that would give this rate would require five ATM-type CMGs, with an overall weight of approximately 1130 kg (2500 lb). To provide this rate with a propulsive system would require approximately 1.6 kg (3.5 lb) of propellant per maneuver. If it is assumed that two maneuvers would be performed per orbit, then the total fuel required per mission would be approximately 1.53 kg (336 lb). To maneuver a total of 1.57 radians (90 deg) would require 15 minutes at the rate specified above. It is possible to increase the maneuver rates of the Shuttle by adding additional CMGs or by increasing the amount of propellant. This would decrease the time required to perform the maneuver but would increase the weight.

In comparison to Shuttle pointing, the azimuth and elevation gimbals provide hemispherical coverage without maneuvering the Shuttle and the mechanical gimbals are capable of slew rates of approximately 0.02 rad/sec (1 deg/sec).

4. IR Telescope On-Orbit Detector Access

On-orbit shirt sleeve access to the focal point of the stellar telescopes is a major desire of many UV and IR scientists. The concept presented in this report does not provide this capability because the entire telescope is mounted external to the pressurized Sortie Lab. Consequently, the NASA/MSFC, COR directed the study to evaluate alternative concepts that would provide this capability for the IR telescope. Four alternatives were defined and evaluated.

The four alternatives had the common characteristics of: (1) the Sortie Lab pressure shell was penetrated so that the detectors were located in the pressurized area and the optics were located in the unpressurized area; (2) pointing of the telescope required maneuvering the Shuttle; (3) detector access was provided through an airlock; (4) the overall f/number of the telescope had to be increased to approximately f/20; and (5) the pointing and stabilization system defined for the alternatives had little or no commonality with the solar payload. The differences that existed for the four alternatives were: (1) the pointing and stabilization systems defined; (2) the type and location of the pressure shell penetrations; and (3) the number of optical elements in the light path.

The evaluation of the four alternatives indicated that all of the approaches were feasible, but that they had disadvantages when compared to the IR telescope configuration derived by this study. The major disadvantage was the need to point the telescope by maneuvering the Shuttle. With the IR telescope viewing constraints of not pointing closer than 1.57 radians (90 deg) to the sun and 0.89 radian (45 deg) to the earth, it is necessary to slew the telescope through large angles twice per orbit to obtain operating efficiencies greater than 32%. To obtain reasonable operating efficiencies of 60% or greater, the slew rate for the telescope should be approximately 0.42 rad/min (24 deg/min) or greater. To provide these slew rates with the Shuttle would be prohibitive in terms of the number of CMGs that would be required. As an alternative, the Shuttle could be maneuvered at these rates with a propulsive system. The quantities of propellant would not be excessive, but this approach is not recommended because of the potential contamination to the IR telescope optics. Other disadvantages associated with the four alternatives evaluated were: (1) the increase in payload weight which ranged from 226 to 4080 kg (500 to 9000 lb); (2) the modification required to the Sortie Lab for the pressure shell penetration; and (3) the requirement for a telescope mount and pointing and stabilization system that would not be common with the solar payload.

As a result of this evaluation, this study retained the IR telescope configuration that did not provide for on-orbit shirt sleeve access to the detectors. However, it is recommended that this issue be studied in detail before deciding on a final concept for the Astronomy Sortie missions.

C. MISSION AND SYSTEMS ANALYSES

The purpose of the mission and systems analyses was to establish an overall systems concept that encompassed the entire sortie mission and to define the interfaces, support hardware, facilities, and personnel that would be required to support the systems concept over the 12-year life of the Astronomy Sortie program.

1. Payload Grouping

The astronomy experiments were grouped into nine payloads, as shown in Table 3. The primary consideration in determining the grouping was the physical size of the telescopes and arrays. Four different payloads are shown for the Stratoscope III and the IR telescopes. In each case, the telescope is the primary experiment and the high-energy array group is the secondary experiment. These payload groupings were the baseline for the study analyses.

Table 3 Baseline Payload Combinations

Payloads / Experiment Groups	Solar Payload	Stratoscope III Payloads				IR Payloads			
	1-2	3AB	3AC	3AD	3AE	4AB	4AC	4AD	4AE
Telescope Groups									
1. PHG	X								
2. XUV SHG + X-Ray + Coronagraphs	X								
3. Stratoscope III		X	X	X	X				
4. IR Telescope						X	X	X	X
Array Groups									
A. Wide Coverage X-Ray		X	X	X	X	X	X	X	X
B. Narrow Band Spectrometer/Polarimetor		X				X			
C. γ-Ray Spectrometer + Low Background γ-Ray Detector			X				X		
D. Large Modulation Collimator				X				X	
E. Large Area X-Ray Detector + Collimated Plane Crystal Spectrometer					X				X

PHG = 100-cm photoheliograph.
XUV SHG = 25-cm XUV Spectroheliograph.
X-Ray = 32-cm X-Ray Telescope.

2. Operations Concept

The operations concept established for the Astronomy Sortie missions, shown in Fig. 3 uses three major areas of payload-oriented activities: the Payload Integration Center (PIC) at MSFC, the Space Astronomy Control Facility (SACF), and the installations required for Shuttle and mission operations and support. The PIC provides the sustaining engineering for the telescopes, arrays, Sortie Labs and pallets throughout the Astronomy Sortie program. This sustaining engineering includes all those activities that are necessary to ensure the delivery of a flight-ready payload to the Shuttle launch site. The SACF is responsible for all experiment operations and for coordinating the space astronomy activities with the established and continuing ground-based research. This facility would have extensive capabilities in astronomy and would accommodate the ground-based scientific personnel that support all mission phases throughout the Astronomy Sortie program. The Shuttle launch and landing site is responsible for loading the payload, monitoring the payload status after installation, and offloading the payload upon completion of the mission. The Space Shuttle mission control center will provide the communication link between the scientific personnel located at the SACF and the on-orbit experiment crew.

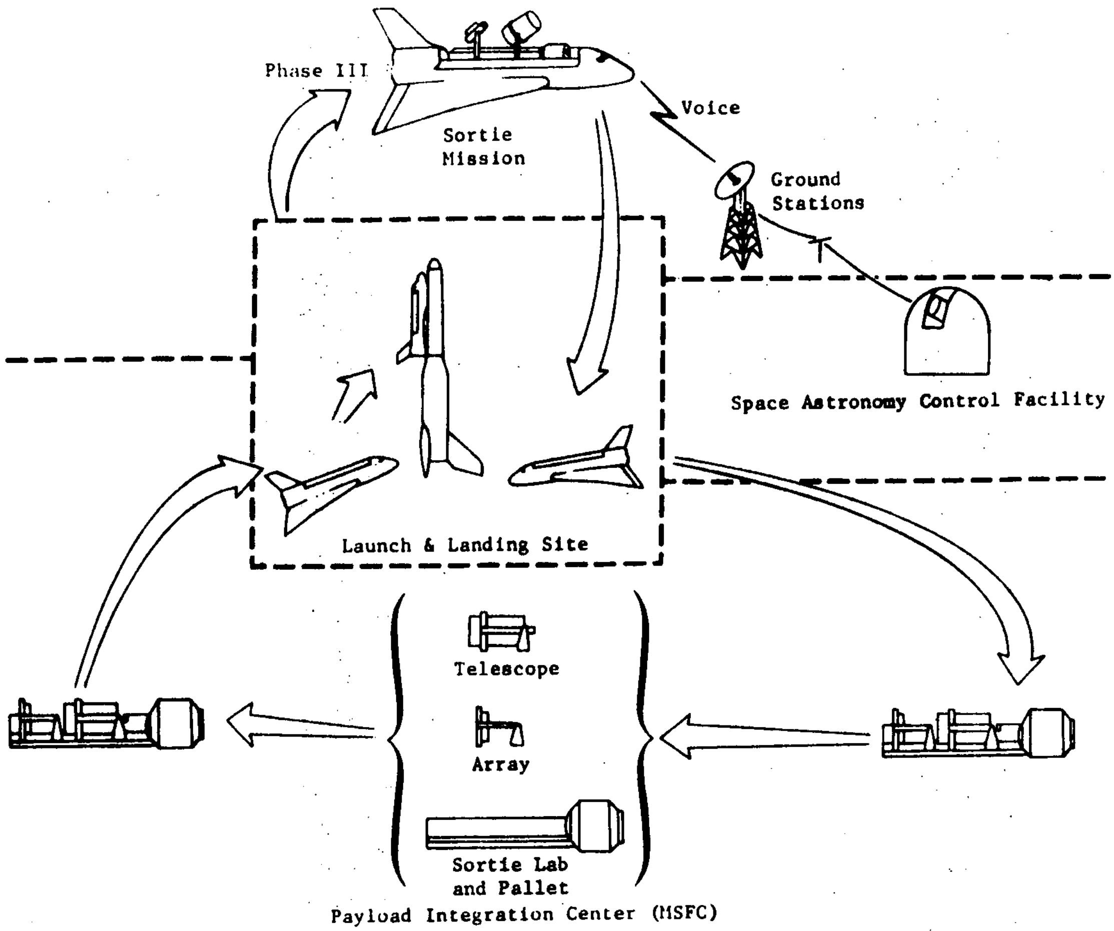


Fig. 3 Operation Concept

3. Turnaround Schedule

The turnaround schedule developed for the astronomy payloads is shown in the top half of Fig. 4. For this schedule, a 212-hr Shuttle processing schedule was used that required the payload to be loaded into the Shuttle at launch minus 132-hr, and allowed 12 hr for installation and verification of the payload. A total of 55 work hours are required at the Shuttle launch site to receive, inspect, and verify the status of the flight-ready payload before installation into the Shuttle. The 135 work hours shown for refurbish and test at the Payload Integration Center (PIC) is the time required to remove one group of telescopes and arrays, refurbish the Sortie Lab and pallet, install a new group of telescopes and arrays, and establish flight readiness. In the development of this turnaround schedule, a 40-hr work week was used for all payload activities at the PIC and the Shuttle launch site up to the time the payload is loaded in the Shuttle. From this point through payload removal the Shuttle processing schedule was used. The shaded time blocks indicate the period that the payload is in the Shuttle Cargo Bay.

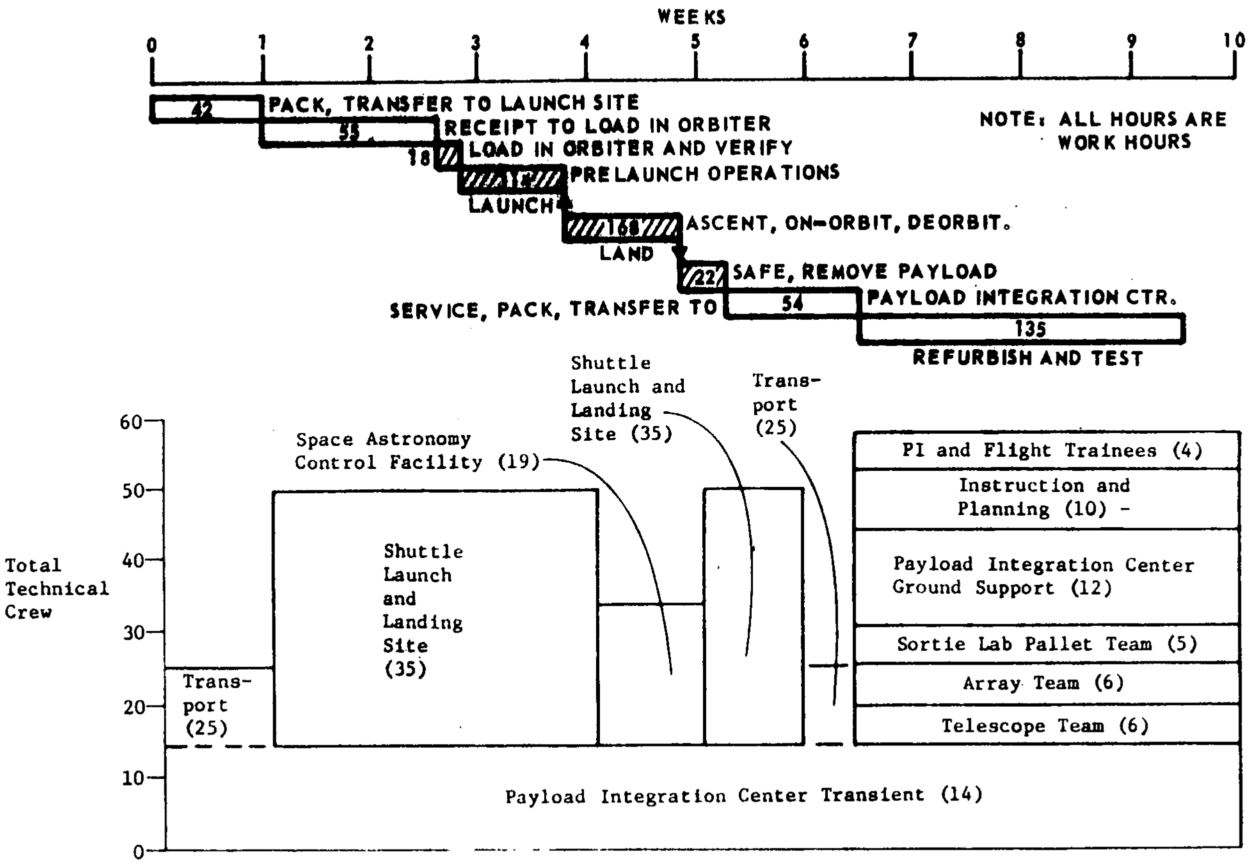


Fig. 4 Turnaround Schedule and Manpower Requirements

4. Manpower Requirements

The direct manpower required to support the turnaround schedule is presented in the lower portion of Fig. 4. These manpower requirements are based on the requirements of each payload and are the direct labor that would be required to support one payload launch. The baseline Astronomy Sortie mission flight schedule designates two flights per year in 1979; three in 1980; five in 1981; seven in 1982; and eight flights per year from 1983 thru 1990. To satisfy this flight schedule, the total number of direct labor personnel for the Astronomy Sortie program would be 198 over the life of the program. This includes 117 direct labor personnel at the PIC, 60 at the Shuttle launch site, and 21 at the SACF. It is emphasized that these personnel are direct labor personnel only. These totals do not reflect the principal investigators and their staffs, nor do they include any administrative, supervisory, or program management personnel.

5. Facility Requirements

To support the Astronomy Sortie program, the PIC will require a building having about 90,000 sq ft of floor space, an entrance and exit airlock large enough for the integrated payload, and Class 100,000 work areas. The facility will provide refurbishment rooms for the telescopes, arrays, Sortie Lab and pallet; a vacuum chamber and deposit area for mirror resurfacing; calibration rooms for the telescopes and arrays; a cryogenic area; machine shop; computer room; and general areas for offices, tool storage, and spares storage. A 50-ton overhead crane will be required in the payload assembly area.

6. Orbital Parameters

The mission analyses performed during the study indicates that orbital parameters for the seven-day sortie missions can be selected to maximize the experiment objectives. This is possible since the long-term effects of the sun, moon, and earth positions and the orbit regression rates are not nearly as important for a seven-day mission as they are for long-term missions.

a. *Solar Payloads* - The basic requirements that solar astronomy place on orbit selection are: (1) continuous sun viewing for the seven-day mission; (2) no viewing through the earth's atmosphere; and (3) minimization of the doppler shift. The three parameters that determine how well these requirements can be satisfied are the beta angle (minimum angle between the sun-line and the orbit plane), orbital altitude, and the time of the year.

To ensure that continuous sun is available during the mission, it is necessary to select an orbit inclination and altitude that will maintain the orbit plane near perpendicular to the sun-line at an altitude that will compensate for changes in the beta angle due to the orbit regression and changes in the sun's position (with respect to earth). To prevent viewing through the earth's atmosphere it is necessary to select an orbital altitude that will always allow the instruments to view the sun without viewing within 400 km (216 n mi) of the limb of the earth. To minimize the doppler shift, it is necessary to select the orbital inclination and altitude so that the changes to the beta angle, and hence the velocity of the payload with respect to the incoming solar rays, do not cause a doppler shift that is greater than the spectral resolution of the solar instruments.

Figure 5 presents the orbital inclination and altitude, as a function of the launch date, that will provide continuous sun viewing for seven days without viewing through the 400 km (216 n mi) atmosphere of the earth. The orbital parameters shown are based on a mission profile that has the beta angle equal to 1.57 radians (90 deg) half way through the seven-day mission. This type of profile minimizes the altitude that is required to prevent viewing through the atmosphere.

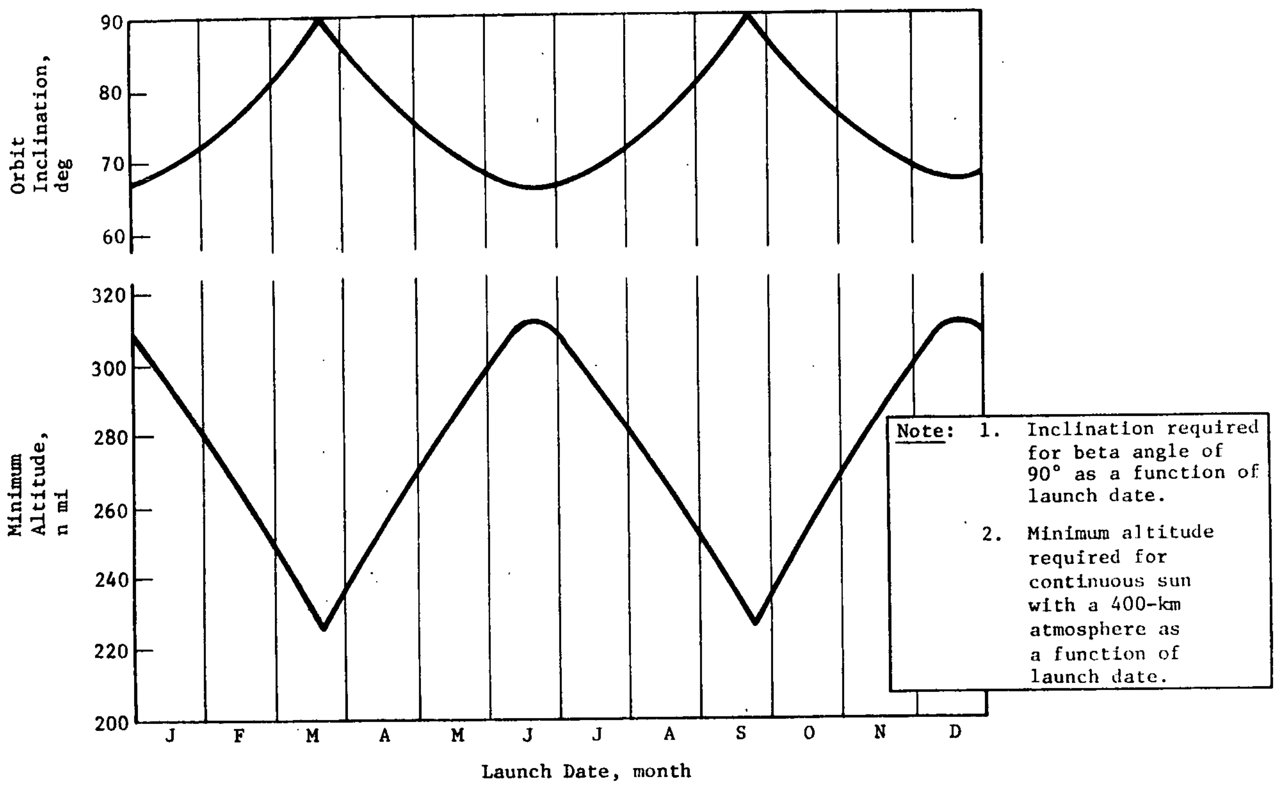


Fig. 5 Inclination and Altitude Required for Continuous Sun

The photoheliograph spectrograph is the only instrument considered in this study that is sensitive to the maximum doppler shift that would be experienced for the orbital inclinations and altitudes shown in Fig. 5. This instrument has a spectral resolution of 0.028 angstroms at a wavelength of 7000 angstroms. To prevent doppler shifts greater than the resolution of the spectrograph, it would be necessary to restrict the orbital inclination as shown in Fig. 6. This figure shows the percentage of the time that the doppler shift is less than the resolution of the spectrograph, and presents the launch dates that would provide 100% on-orbit operations with doppler shifts less than the resolution of the instrument. The doppler shifts that would be experienced during the mission are a function of the orbital inclination and altitude as well as the spectral range of the instrument and can be expressed as:

$$\text{Doppler shift } (\text{Å}) = \frac{\cos\beta\, V_{\text{orbital velocity}}}{V_{\text{speed of light}}}\,\lambda\ (\text{Å})$$

where

β = Beta angle,

$V_{\text{orbital velocity}}$ = Velocity of the payload,

λ = Instrument wavelength, Angstroms.

The doppler shift for a beta angle of 1.34 radians (77 deg) and an altitude of 463 km (250 n mi) would be 0.012 angstroms at a wavelength of 2000 angstroms and 0.040 angstroms at 7000 angstroms. In comparison, the resolution of the photoheliograph is 0.008 angstroms at 2000 angstroms and 0.028 angstroms at 7000 angstroms. Consequently, to prevent the doppler shift exceeding the resolution of the spectrograph it is necessary to restrict the launch dates as shown on Fig. 6.

b. *Stellar Payloads* - The basic requirements that stellar payloads place on orbit selection are: (1) maximize dark time; (2) maximize celestial sphere availability; (3) minimize sun, moon, and earth interference; (4) maximize the cone of continuous visibility; and (5) do not view through the atmosphere of the earth.

An elliptical orbit was investigated to determine if there was a significant increase in dark time as compared to a more conventional circular orbit. The results of this analysis indicated that a small increase in dark time (less than 3 min maximum) could be obtained with elliptical orbits. Since this is not a significant increase in dark time, and because the elliptical orbits do have operational disadvantages it was recommended that only circular orbits be considered for the stellar payloads.

To maximize the percentage of the celestial sphere available during the seven-day mission, the stellar payloads should be flown during a new moon condition. This condition places the moon near the sun and minimizes the percentage of the sky that cannot be viewed due to look angle constraints on the moon.

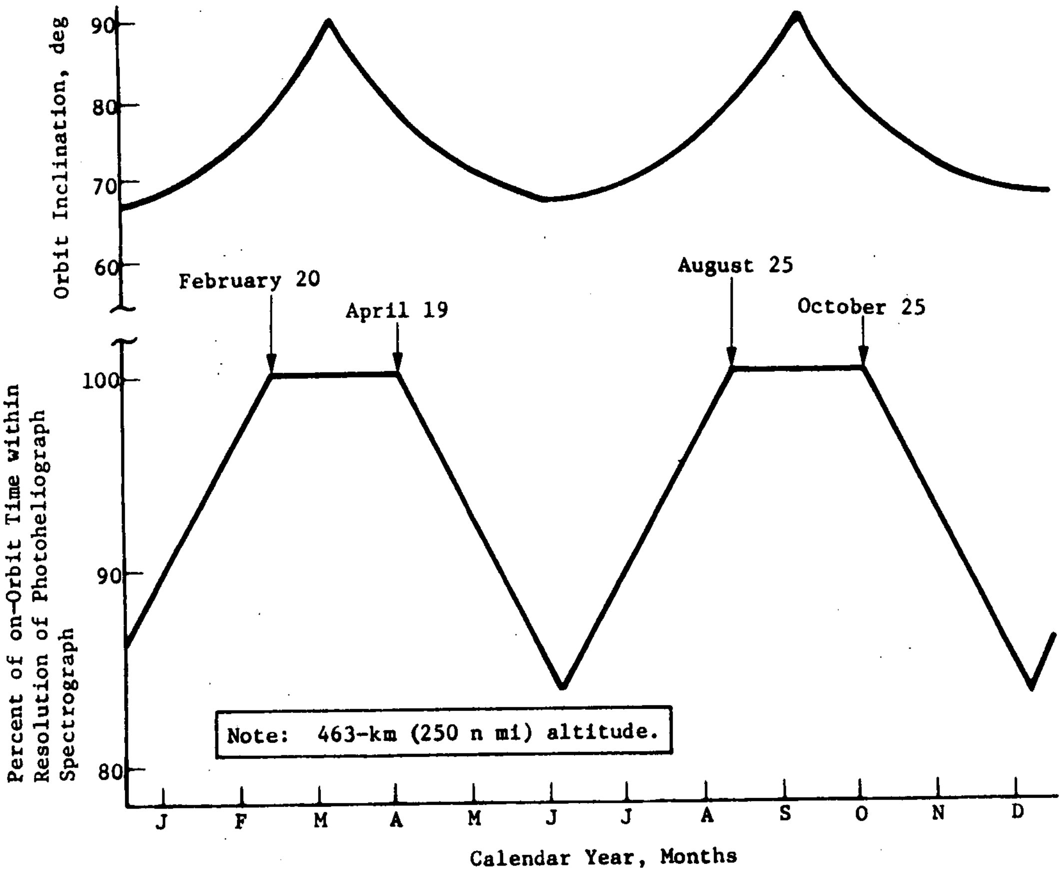


Fig. 6 Photoheliograph Constraint on Inclination

Figure 7 shows the percentage of the celestial sphere that is viewable for various look-angle constraints about the sun, earth, and moon. Note that flying these missions during the new moon phase adds significantly to the viewable portion of the celestial sphere at the higher angles of constraint and that this advantage decreases to near zero at an angle of 0.524 radian (30 deg) about the sun and 0.262 radian (15 deg) about the earth and moon. At the 0.524 radian (30 deg) constraint about the sun and 0.262 radian (15 deg) about the earth and moon, some 93% of the celestial sphere may be observed. Thus, little is gained by reducing the look angle constraints below this level unless a cone of continuous visibility larger than 0.21 radian (12 deg) is desired.

Figure 8 shows the variation in the cone of continuous viewing for a circular orbit of 463 km (250 n mi) altitude. For this altitude, the maximum full angle cone viewable throughout the entire orbit is 0.558 radian (32 deg) at the limit imposed by the 185 km (100 n mi) atmosphere of the earth. The look angle constraint about the earth for this maximum cone of continuous viewing is 0.087 radian (5 deg).

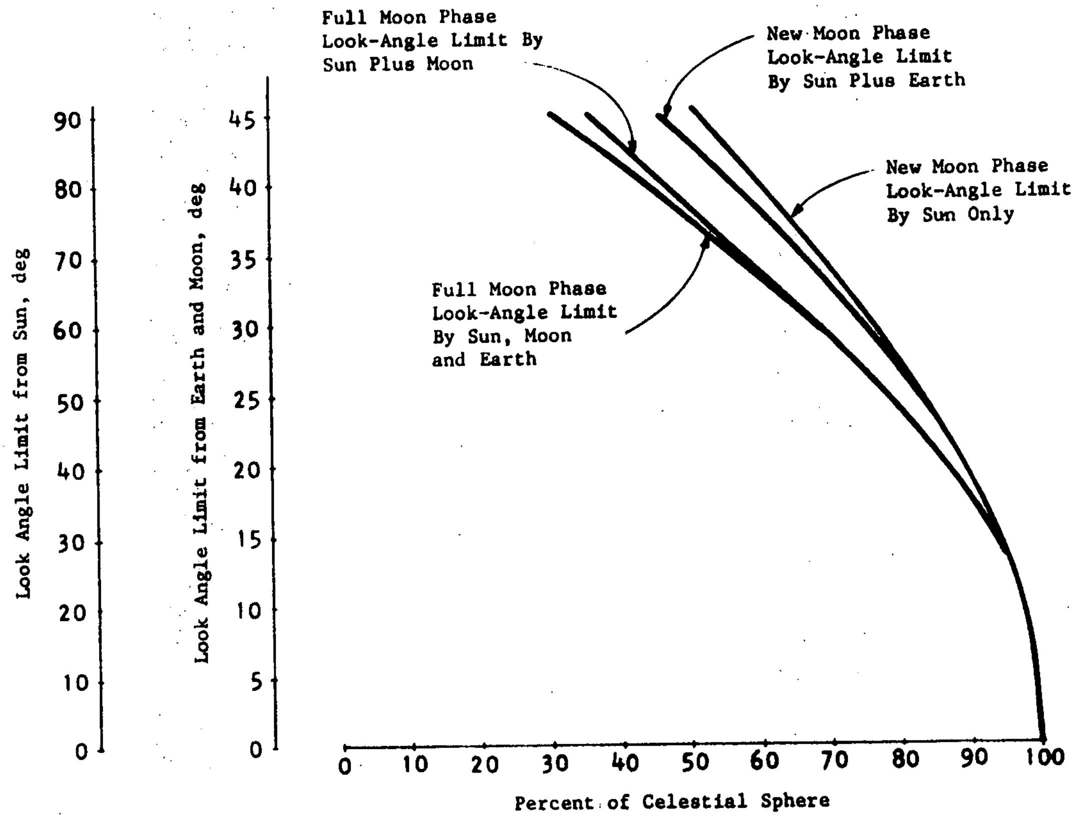
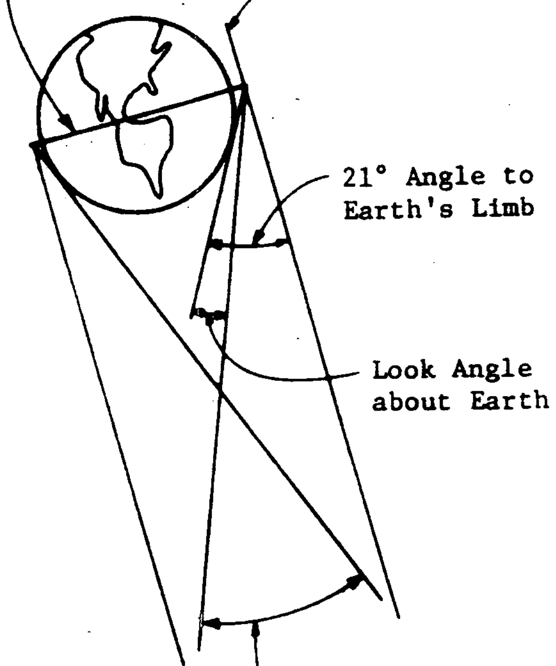


Fig. 7 Look Angle Constraint Impact on Celestial Viewing

An advantage of the seven-day sortie mission is that the orbit inclination and altitude can be selected to provide the desired area of the celestial sphere for viewing. This flexibility allows each mission to be tailored to a specific area of the celestial sphere.



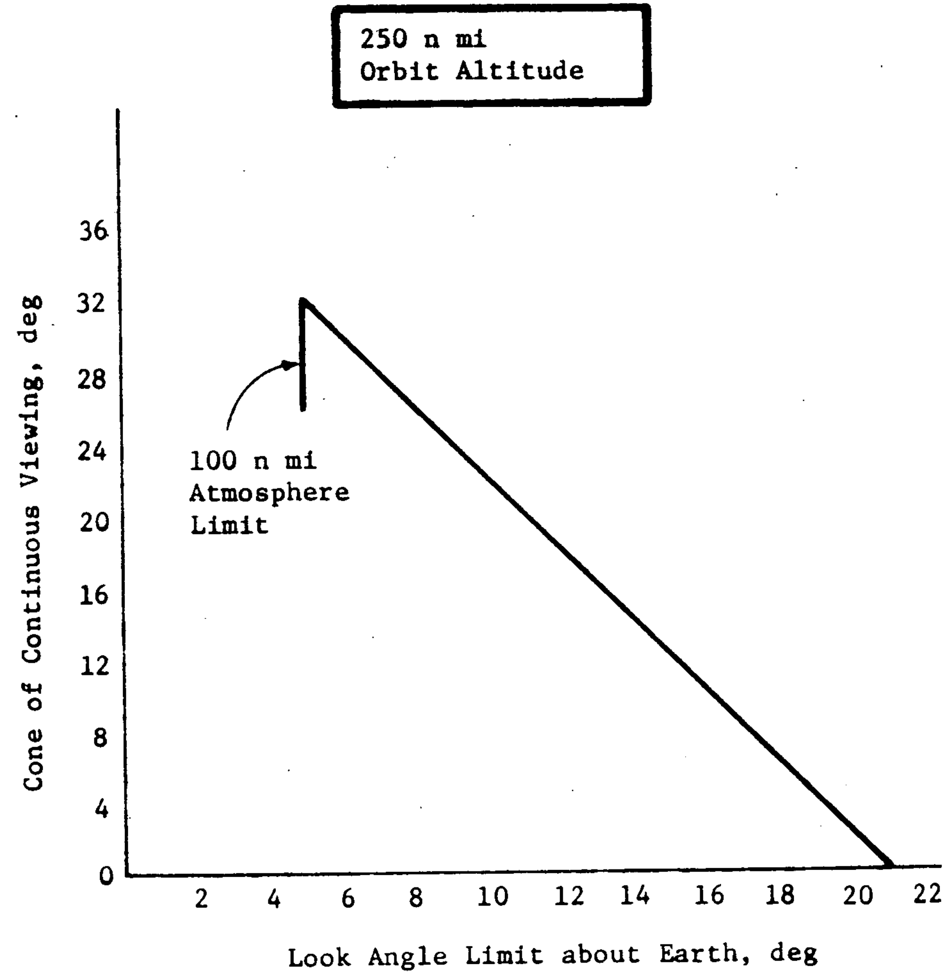


Fig. 8 Cone of Continuous Visibility

D. SUBSYSTEM ANALYSES

The purpose of the subsystem analyses was to define the subsystems required to support the baseline ASM experiments. Analyses, including tradeoffs, were conducted to define the structures, thermal control, stabilization and control, controls and displays, data management, and electrical subsystems. The subsystem definitions are to a depth sufficient to establish feasibility, compatibility between subsystems, adequate performance levels, physical characteristics, interface definitions, and compatibility with manned orbital operations.

1. Structures

A special emphasis task of the study was to define a 1-m aperture, cooled IR telescope concept. Because of the need to achieve and maintain an operating temperature of approximately 28°K on the telescope structure, the cryogenic system design exerted a strong influence on the concept. While the selected, stored, integral tank cryogenic system is similar to that shown in the NASA Blue Book, two alternative systems were considered. Both incorporated separate tanks with circulation of the cryogenic fluid by pumps. The first system located the tanks and active components on the pallet and had flexible lines to carry the fluid to the telescopes. The second system was mounted to the aft structure of the telescope. These alternatives were not adopted for the following reasons:

1) The remote location of the first system involved carrying long lines across the deployment and gimbal joints, with the resulting large heat leaks and undesirable torques on the gimbals.

2) The second system eliminated the long lines but placed rotating machinery directly on the telescope. In addition, the cg shift due to fluid depletion in the separate telescope-mounted tank would complicate the telescope stabilization system.

The selected system has an integral cryogenic tank in the form of an annulus of a cylinder. Capillary screens within the tank provide circulation of the fluid to assure wetting of the tank walls without the use of rotating machinery, such as pumps. This approach minimizes cg shift due to fluid depletion, eliminates vibration caused by rotating equipment, simplifies the fluid distribution system, and ensures minimum heat leaks and thermal gradients by using the cryogenic tanks as the telescope structure.

Having selected a stored cryogenic system, the decision was made to cool the telescope to operating temperature before Shuttle launch. This was done to reduce the amount of fluid to be carried to orbit by approximately 2500 kg (5500 lb) and to reduce the weight and size of the tank structure.

The design requirements of the cryogenic subsystem, along with the requirement to be compatible with the payload configuration concept (Fig. 1) adopted early in this study, had major impacts on the selected structural approach. The approach features an annular cryogenic tank with the inner wall of the tank forming the viewing tube of the telescope. This places the cryogenic supply in intimate contact with the structure which is "seen" by the telescope optical elements and detectors, and eliminates possible temperature gradients in this structure. Support structures for the optics and the detectors are attached to the inner wall of the tank and are cooled by conduction and radiation to the cold tank wall. The tank is designed to contain cryogenic gasses between programmed ventings spaced at 3-hr intervals or longer to be compatible with Shuttle capabilities. This minimizes possible contamination of the optical elements of the payload since non-viewing periods can be used for venting. An adapter structure, designed for maximum rigidity with minimum heat leaks, supports the telescope on the gimbal assembly of the telescope mount. The adapter structure allows the telescope to mount to the same gimbal assembly used for the other ASM telescopes.

Invar was selected as the primary structural material because of its favorable thermal characteristics.

The concept presented represents a feasible approach for the design of a cooled IR telescope, and should be useful as the basis for further development work.

The experiment mounts shown in Fig. 9 employ the wide-angle gimbal mount concept, providing hemispherical viewing capability for the telescopes and arrays. The telescope mount is designed to accommodate any of the telescope groups baselined for the ASM program, while the array mount accommodates any of the baseline array groups.

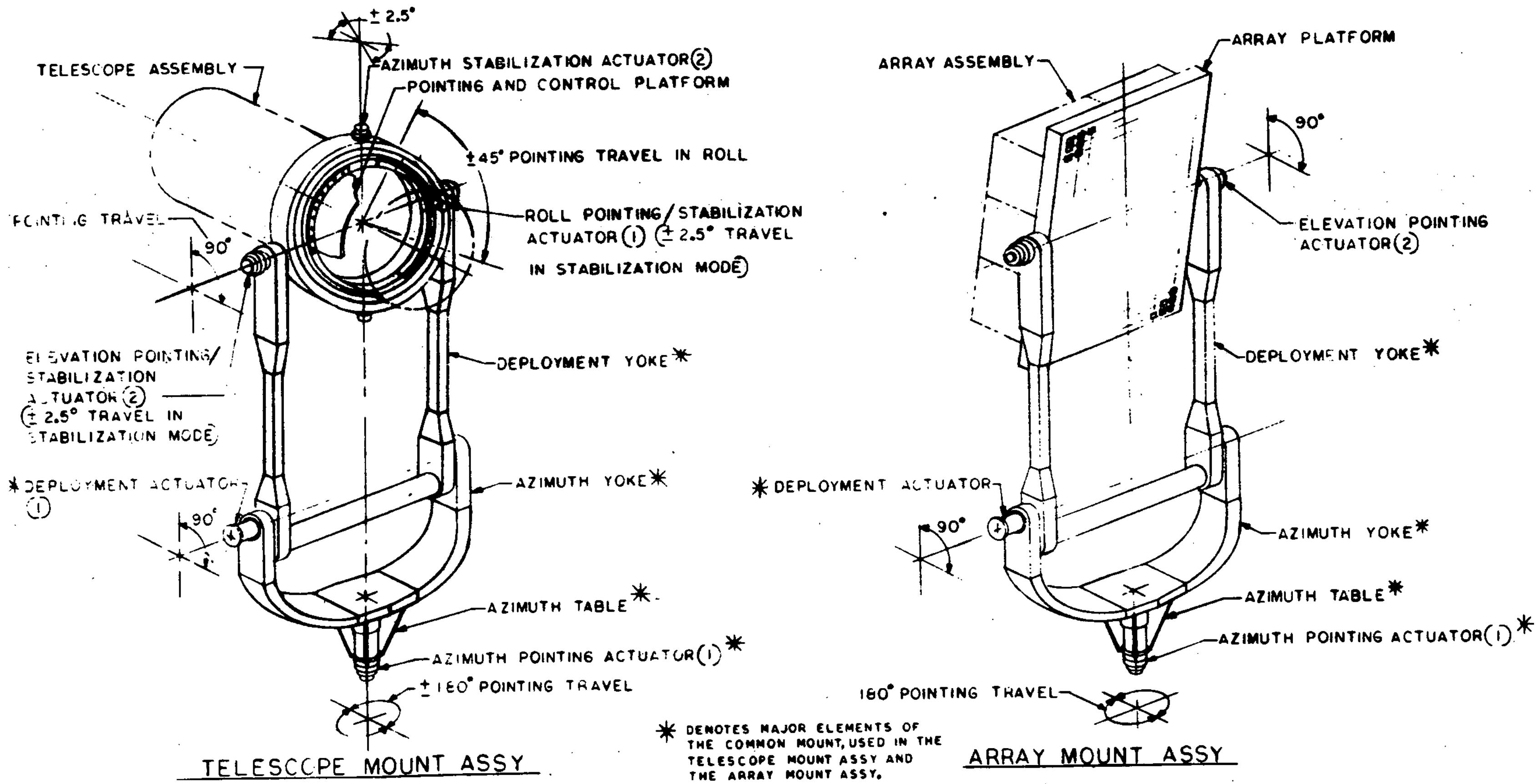


Fig. 9 Experiment Mounts

The common mount is used as the basic building block for the telescope and array mounts. This approach minimizes the number of hardware elements that must be developed. The common mount consists of the azimuth table, azimuth pointing actuator, azimuth yoke, deployment yoke, and deployment actuator. Addition of the telescope gimbal assembly and the elevation pointing/stabilization actuators to the common mount creates the telescope mount. The gimbal assembly and actuators incorporate the fine pointing and stabilization capabilities required for all telescopes, plus the capability for roll orientation required by the photoheliograph. The array mount requires the addition of the array platform and elevation pointing actuators to the common mount. Fine pointing and stabilization are not required by the arrays.

Operation of the telescope mount begins with the release of launch locks (not shown) and a 90 deg rotation of the deployment yoke to move the telescope out of the payload bay. Coarse pointing of the telescope within the bounds of a hemisphere is accomplished by rotating the azimuth yoke and positioning the gimbal assembly by the elevation portion of the dual-purpose elevation pointing/stabilization actuator. The pointing portion of the roll pointing/stabilization actuator is used only to orient the photoheliograph during observations using the spectrograph. Brakes are incorporated in the actuators to hold the desired coarse orientation. Fine pointing and stabilization is accomplished from this orientation by actuating the stabilization portion of the elevation pointing/stabilization actuator, the gimbal-mounted azimuth stabilization actuator, and the stabilization portion of the roll pointing/stabilization actuator. Operation of the array mount is identical to that of the telescope mount, except that the fine pointing and stabilization capabilities are not incorporated.

The very precise pointing and stabilization requirements of the baseline ASM telescopes imposed the need for rigid mounts and precise positioning of the experiments by the actuators. The design approach that was adopted uses members with large cross sections for maximum rigidity. Launch locks alleviate the high loads that would otherwise be imposed on the structures and actuators. To provide smooth friction-free rotation of elements about the fine pointing and stabilization axes, and to eliminate the backlash of gear trains, the actuators incorporate direct drive dc motors and flexible suspensions.

Details of the design approaches, along with mass properties data and stress analyses are included in Volume III of this report. Subjects covered are the IR telescope, telescope and array mounts, specialized array mounts, the baselined ASM telescopes and arrays, the payload accommodations required for all payloads, and each of the nine complete ASM payloads.

2. Thermal Control

The general thermal design philosophy was to use passive thermal control methods, where possible, to regulate the heat flow across the telescope boundaries and obtain the desired temperature levels. Passive control is desirable because of its simplicity and reliability. These methods involve the use of surface coatings and insulation. Active or semi-active methods are used only where passive methods will not provide the required temperature control. Thermal decoupling of the telescope tube from the fluctuations of the external environment is a thermal design approach common to all the telescope types. Low α/ε coatings on the outside surface of the meteoroid shield, and multilayer insulation blankets on the interior structure are the primary means of providing low sensitivity to variations in the external orbital environment.

The telescope insulation is also beneficial to controlling the transient thermal effects imposed during launch and initial orbit (Shuttle doors closed). The long time constant provided by the insulation results in a slow response of the telescope to the Orbiter temperature excursions. For the hot conditions analyzed, the Orbiter bay external surfaces varied between 500°F and -230°F. The corresponding excursion in the telescope average temperature was less than 1°F.

During the operational phase the presence of the Orbiter will provide sources of energy interchange with the telescopes and influence the view factors to space and the earth. This impact on the external thermal environment was analyzed in detail using a heat rate model representing the Orbiter vehicle with astronomy payload deployed. The model consists of 131 external surface nodes including 33 that define the telescope. Transient calculations were made using available computer programs to determine grey body radiation exchange factors ($\mathcal{F}$) and absorbed orbital heat fluxes. Mutliple reflections and shadowing effects were accounted for in the analysis. Further computer analysis was performed to determine the IR contribution to the thermal environment from the Orbiter and payload surfaces. A simplified boundary condition was subsequently generated for each surface node representing the total thermal environment in the form of equivalent space sink temperatures. Table 4 presents a summary of the thermal environment for the IR telescope in terms of fluxes averaged around the cylindrical surface and averaged over one orbit period. The impact of the proximity of the Orbiter/payload on the thermal environment of the telescope is shown by comparison with a free-flying telescope. The overall impact is an increase in the effective thermal environment for the orbital parameters and orientation studied. The telescope was oriented with the longitudinal axis perpendicular to the solar vector, the Orbiter longitudinal axis along the solar vector, and the orbit plane inclined 90 deg to the solar vector. Equivalent space sink temperatures for the IR telescope are shown in Fig. 10 to range between -280°F and 90°F. Equivalent space sink temperatures were determined to range between -190°F and 50°F for the experiment mounts, between -340°F and 50°F for the arrays, between -190°F and 10°F for the pallet, and between -130°F and 5°F for the ends of the Sortie Lab.

Table 4 IR Telescope Thermal Environment Summary

Heat Source	Absorbed Flux (Btu/ft^2-hr) Orbiter Deployed	Free Flying
Solar	29.2	29.4
Albedo	0.243	0.95
Earth IR	13.3	22.3
Reflected	1.9	0
Orbiter Payload IR	-1.9	0
Total	42.74	52.6
$\mathcal{F}$ to Space	0.55	0.88
Equivalent Space Sink Temperature	1°F	-28°F

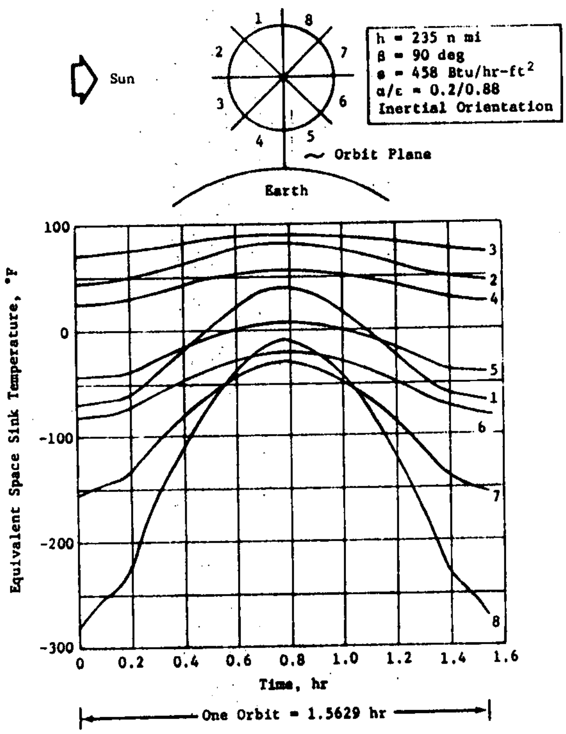


Fig. 10 IR Telescope Equivalent Space Sink Temperatures

The thermal studies of the telescopes show that the passive thermal control methods employed, and discussed earlier, need to be supplemented by other approaches depending on the nature of the experiment. For the IR telescope (which was selected for detailed studies using a 102 node thermal math model) the entire telescope was enclosed within a jacket of liquid neon. The objective of an upper temperature limit of 28°K for the optics and telescope barrel is achieved by allowing the neon to boil at a pressure between 0.43 and 1 atm, thus controlling the telescope within 24.5°K and 27.2°K. During the 3-hr neon vent hold periods the thermal capacitance of the system is such that the maximum increase in average telescope temperature is 0.6°K. For a seven-day mission the computed value for the loaded quantity of neon is 785 lb, including margins.

In the case of the stellar astronomy telescope, Stratoscope III, the optics are electrically heated to compensate for the radiation heat loss to space through the optics viewing aperture. The thermal control power consumption, including heaters for the primary mirror, primary mount, and secondary mount, is calculated to be 78 W to maintain the optics at 70°F.

The principal consideration for the photoheliograph and coronagraphs is one of removing the solar heat load that enters the telescope apertures. This is significantly reduced by heat shield mirrors that reflect the unwanted solar energy back into space again, protecting the instruments from undue heating. Preliminary calculations show that the absorbed solar energy cannot be dissipated by direct radiation to space only, otherwide mirror temperatures in the range 500°F to 600°F will result. A heat pipe system is recommended to transport this absorbed energy to radiators that emit to space.

A major problem associated with all four solar telescopes is to minimize temperature gradients in the structure so that alignment can be maintained between the optical components. Further, it will be necessary to supply some heat to the interior structure to make up heat losses through the sidewalls (zero direct solar incidence orientation) and through the open aperture to maintain the "room temperature" levels. For purposes of simplicity it is recommended that this heat be introduced with zoned and thermostatically controlled electrical heaters to minimize gradients.

The heater power required for each telescope and the optics heat rejection requirements are presented in Table 5. The indications are that for the photoheliograph a heat pipe system that redistributes the unwanted solar energy from the optics to the structure would be an attractive alternative approach in a power-limited mission.

Table 5 Solar Telescope Heat Balance Summary

	Mirror Heat Balance				
Telescope	Mirror	Absorbed Solar Flux, W	Equilibrium Temperature, °F	Cooling Load at 75°F, W	Internal Structure Heater Power, W (25% Margin)
100-cm Photoheliograph	Primary	154	552	142	184
2.45-cm Coronagraphs 4.0-cm	Heat Shield	9 61	566 520	8 56	6 27
32-cm X-Ray	Grazing Incidence	∿1	70	N/A	28
25-cm Spectroheliograph	N/A	N/A	N/A	N/A	65

3. Stabilization and Control

The ASM stabilization and control subsystem provides the experiment pointing and stabilization required by the various baseline ASM experiments. The ASM stabilization and control subsystem consists of two elements: (1) a Shuttle Orbiter stabilization and control system; and (2) an experiment gimbal system.

An important consideration in selecting a Shuttle Orbiter stabilization and control system is the attitude in which the Orbiter is stabilized. This attitude has a direct impact on the required resources such as fuel or angular momentum storage requirement. Four attitudes were considered:

1) An inertial attitude with the vehicle's longitudinal axis (X axis) perpendicular to the orbital plane (X-POP);

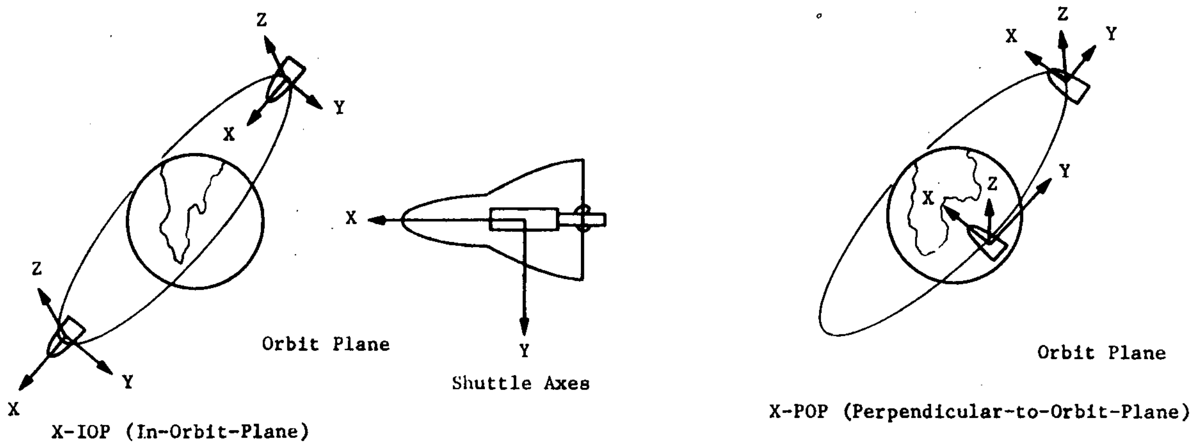
2) An attitude in which the vehicle longitudinal axis is perpendicular to the orbital plane with a transverse axis (Z axis) pointing to the local vertical (X-POP ZLV);

3) An inertial attitude with the vehicle longitudinal axis in the orbital plane (X-IOP);

4) An attitude in which the vehicle longitudinal axis is in the orbital plane with a transverse axis (Z axis) pointing to the local vertical (X-IOP ZLV).

For the two local vertical attitudes, X-POP ZLV and X-IOP ZLV, the Shuttle Orbiter rotates at the orbital rate ω_o about its X and Y axes, respectively, in order to keep its Z-axis pointed toward the earth. All of the baseline ASM experiments are required to be inertially pointed. Each experiment, therefore, would require a wide-angle stabilization system to remove this rotational motion ω_o, thus significantly increasing the complexity of the overall system. The two inertial attitudes are shown in Fig. 11 along with their gravity gradient angular momentum requirements for both a propulsion and a CMG stabilization system. These momentum storage requirements reflect the relative size, in terms of fuel or momentum storage requirements, for each stabilization system. For example, an X-IOP propulsion system has a momentum (and fuel) requirement approximately 13 times larger than its corresponding X-POP system. Similarly, the CMG storage requirement for the X-IOP attitude resulting from these gravity gradient torques is approximately 3.5 times larger than for the X-POP CMG system.

This inertial X-POP attitude is the optimum inertial attitude from the standpoint of system size as it corresponds to the lowest gravity gradient torque environment. For this reason, the inertial X-POP attitude was selected as the ASM baseline attitude for the Shuttle Orbiter.



Gravity Gradient Angular Momentum Stabilization Requirements	X-IOP	X-POP
Propulsion System	66760 N-m-s/Orbit (49295 ft-lb-sec/Orbit)	5115 N-m-s/Orbit (3760 ft-lb-sec/Orbit)
CMG System	7500 N-m-s/Orbit (5530 ft-lb-sec/Orbit)	2240 N-m-s/Orbit (1650 ft-lb-sec/Orbit)

Fig. 11 Shuttle Inertial Attitude

Three stabilization systems were considered for stabilizing the Shuttle Orbiter in its inertial X-POP attitude:

1) The Shuttle Orbiter's baseline attitude control propulsion system (ACPS);

2) A low-thrust reaction control system (RCS);

3) A double gimbal CMG system.

The baseline ACPS is a 1.8 kN(400 lbf) monopropellant hydrazine system with a minimum attitude deadband of ±8.75 mrad (±0.5 deg). For an ACPS attitude deadband of ±8.75 mrad, the control axes of the orbiter will limit-cycle back and forth between the attitude deadband limits because of the large thrust level associated with this system. With limit cycling, the ACPS consumes fuel at the rate of 1790 kg/day (815 lb/day). This large fuel consumption results in a heavy ACPS stabilization system and a system that is a probable source of severe experiment contamination.

As an alternative to the baseline ACPS, a low-thrust RCS was sized to reduce the limit cycling between attitude deadbands. The resultant low-thrust RCS is a 18 N (4 lbf) bipropellant system with a fuel consumption of 46 kg/day (21 lb/day). Table 6 is the Shuttle Orbiter contamination model used in this study. Note that even this low-thrust RCS doubles the amount of unprogrammable contaminates that are discharged. This will increase the probability of ASM experiment contamination by increasing the volume of contaminates expelled and by introducing new elements into the cloud surrounding the Orbiter. Another disadvantage of this RCS is that a new system would have to be integrated with the Shuttle Orbiter before each ASM mission or installed as a permanent system.

Table 6 Contamination Model

Source	Material	Rate of Discharge	Program Discharge	ACPS	Low Thrust RCS	CMG
Fuel Cell Dump	H_2O	190 lb/day*	Yes	✓	✓	✓
Waste	H_2O	3.3 lb/man-day*	Yes	✓	✓	✓
Shuttle Cabin Leakage	$N_2 + O_2 + H_2O$	9.3 lb/day*	No	✓	✓	✓
Sortie Lab Leakage	$N_2 + O_2 + H_2O$	10 lb/day†	No	✓	✓	✓
Outgassing	Organic Gases & Particles	1 lb/day§	No	✓	✓	✓
ACPS (±0.5 deg)	H_2O, CO, etc	815 lb/day¶	No	✓		
Man & Trans RCS	H_2O, CO, etc	21 lb/day¶	Yes		✓	
RCS Stabilization	H_2O, CO, etc	20 lb/day¶	No		✓	

*Data extracted from RAM Task 4.2/4.3 Review, dated 10 Dec 1971.

†Data based on *Sortie Can Conceptual Design*, ASR-PD-DO-72-2, March 1, 1972.

§Estimated based on Skylab model.

¶Based on propellant requirements.

A double gimbal CMG Shuttle Orbiter stabilization was sized using three Skylab ATM CMGs. The major advantages of this system are: (1) the contaminants associated with an RCS are eliminated; (2) the CMGs are integrated with the payload before the ASM payload is integrated with the Orbiter, simplifying the ground operations associated with the Shuttle Orbiter; (3) the mission growth capability of extending the ASM mission beyond the baseline seven-day mission exists without increasing the size of the CMG system; and (4) the stabilization capabilities of this system are better than either of the two candidate gas propulsion systems. The disadvantages of this CMG system are: (1) a new system is added to the ASM payload; (2) for a baseline seven-day mission, the weight of the CMG system is approximately three times the weight of the low-thrust RCS; and (3) the power requirements of the CMG system are approximately 150 W higher than for the two other candidates.

The selected baseline ASM telescope pointing and fine stabilization system is shown in Fig. 9. This system consists of three principal elements, a deployed wide-angle gimbal for pointing the telescopes in azimuth and elevation, a flex-pivot suspension system similar to one used by the Skylab ATM system for providing fine stabilization about these two axes, and a servoed roll ring to point and stabilize the telescope in roll. This system was selected over various gas bearing concepts because of its projected low technical risk, low weight and volume requirements, and low development costs. The high-energy arrays are pointed using a wide-angle gimbal system that is mechanically identical to the telescope system. After the arrays are pointed using the wide-angle gimbals, the gimbals are locked and stabilization is supplied by the CMG-stabilized Shuttle Orbiter. No roll ring is needed since the arrays have no roll pointing requirement.

Figure 12 is a functional block diagram of the ASM stabilization and control subsystem. The subsystem hardware complement consists of:

1) Three double gimbal control moment gyros (DGCMGs);

2) Two inertial measurement unit packages (three gyros per package);

3) Four strapdown star trackers;

4) One telescope fine attitude error sensor;

5) Two wide-angle gimbal pointing systems (one for the telescopes and one for the high-energy arrays);

6) One telescope fine stabilization system.

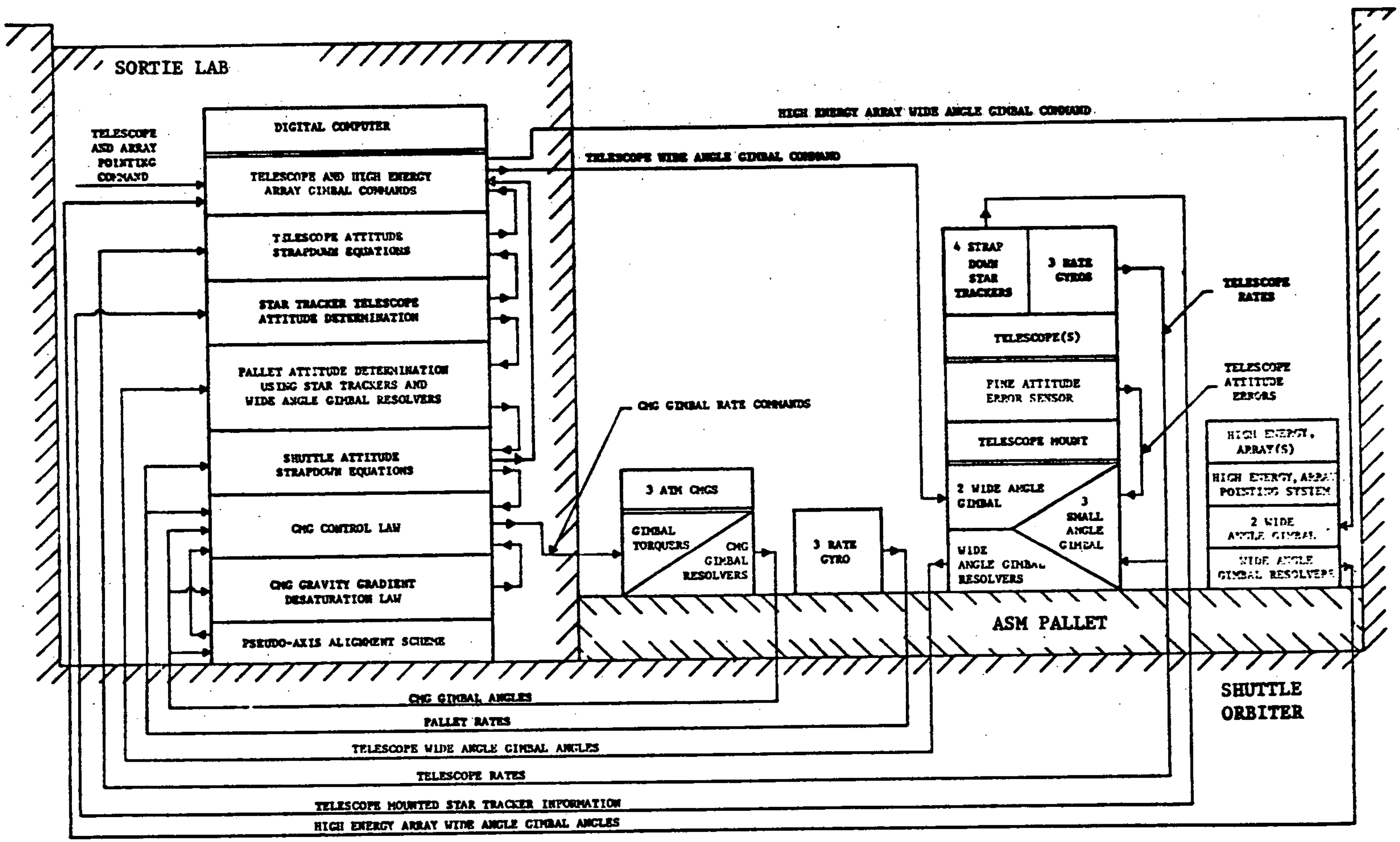


Fig. 12 Functional Block Diagram of ASM Stabilization and Control Subsystem

The subsystem digital computational requirements are performed using a centralized computer in the Sortie Lab.

4. Controls and Displays (C&D)

The objectives of the C&D study effort were to select a C&D concept and provide a console preliminary design. This effort was developed based on the definition of experiment and support subsystems functional requirements and consideration of the following program guidelines:

1) Payload C&D requirements limited to seven-day sortie missions;

2) Payload command and data functions managed via a centralized data management computer;

3) Minimum hardware interface to the C&D console;

4) Normal experiment operation by one unsuited crewman.

The baseline ASM experiments was analyzed and the C&D functional requirements defined. A comparison of the functional requirements resulted in the identification of in excess of 50% commonality of functions. To capitalize on this functional commonality, an effort was undertaken to conceive consoles that maximized the panel area common to all payloads and thereby reduce the degree of modification required to satisfy the payload-unique C&D requirements.

Two basic C&D concepts were considered: dedicated and computer interactive. The dedicated concept provides a console that uses conventional dedicated components to satisfy a specific or, via time sharing, a grouping of specific functional requirements. As such, the dedicated-type console must be uniquely configured via hardware modification to satisfy the functional requirements of the nine defined payloads. The study effort determined that a dedicated-type console, with a panel area common to all payloads complemented by panel areas providing payload experiment-unique C&D, was feasible. This concept defined unique panel areas, one for each experfiment, which are modularly added to and removed from the basic common C&D panel and structure to provide the C&D required for each payload. However, consideration of hardware to satisfy functional requirements and crew station layout, such as sequencing of controls, minimizes the panel area having inter-payload commonality.

The alternative concept initially considered was the computer interactive console wherein the C&D console is common to all payloads and the requirements are satisfied by software modifications.

However, this concept was considered overly restrictive to the experimentor in terms of providing unique displays. Therefore, the concept was modified to a hybrid configuration combining computer interactive multipurpose C&D with conventional function dedicated C&D. The interactive portion of the console comprises multipurpose cathode ray tube (CRT) indicators and appropriate command and data entry keyboards interfaced with a central data management computer. The dedicated portion of the console comprices modular rack-type chassis that are provided based on specific unique payload C&D requirements.

A comparative analysis of the characteristics of the dedicated versus hybrid concepts was performed and is summarized as follows:

Characteristic	Preferred Concept
Crews:	
Training	Dedicated
Operational Error	Hybrid
Task Performance Time	Hybrid
Information Presentation	Hybrid
Equipment:	
Power	Dedicated
Weight	Hybrid
Commonality	Hybrid
Maintainability	Hybrid
Complexity	Dedicated
Interface	Hybrid
Availability	Dedicated
Flexibility	Hybrid

As a result of this analysis, and particularly in consideration of the high degree of flexibility of the hybrid concept to accommodate payload redefinition, this concept was recommended for furhter study and preliminary design.

The hybrid C&D console concept provides a flexible cost-expedient C&D system that minimizes the impact of satisfying the C&D requirements of the various ASM payloads. The versatility of the software-oriented interactive displays provides the capability of displaying information in a multitude of formats. The optimum format for each instrument and support subsystem may be determined and implemented without impacting the basic hardware configuration of the system. Additionally, as greater amounts and more in-depth information can be displayed than with function/hardware dedicated C&D, crew dependence on ground communications may be significantly reduced. System reconfiguration to accommodate the differing C&D requirements of the various payload configurations is implemented primarily by software formatting. The dedicated C&D are modular add-ons implemented via a hardwire interface with the payload and provide the experimenter with an added degree of flexibility in the implementation of unique C&D requirements.

The ASM payload C&D console has been conceived with a primary aim of satisfying the experiment and experiment support subsystems C&D requirements. However, a brief review of related study efforts indicates that both the Sortie Lab Conceptual Design and the Sortie RAM studies concluded that the module subsystems did not require continuous crew monitoring of parametric data and that monitoring should be performed at the experiment console. Considering that the current ASM baseline provides for a two-man crew, operating in shifts with a minimum of overlap, a more efficient utilization of crew timelines appears feasible if module subsystems are monitored and corrective actions initiated from the payload C&D console. Therefore, a caution and warning terminal and subsystems advisory indicators have been included in the console to provide the operator immediate visual cues of malfunctions without necessitating translation to an alternate work station. In response to the malfunction cue, the operator addresses the data system to provide the appropriate subsystem data display on one of the CRTs and commands corrective action via the keyboards.

The overall console configuration is illustrated in Fig. 13. The crew station provides the command center for payload operation and monitoring of module subsystems. The arrangement of the C&D components provides for normal operation by a single crewman; however, two-crewman operation may be accommmodated, with the second crewman limited to supporting activities, primarily associated with operation of the experiment-dedicated equipment chassis.

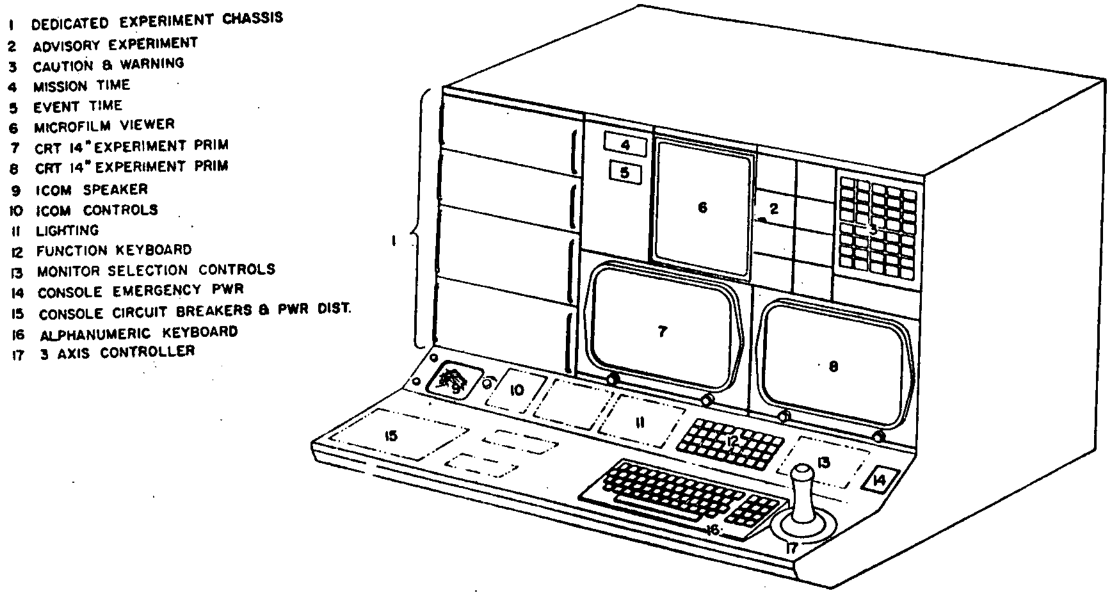


Fig. 13 ASM Payload Control and Display Console

5. Data Management

The Sortie Lab data management subsystem (DMS) performs all onboard formatting and storage of payload data, computations, and commands and controls of instrument and subsystem sequencing. Shuttle pallet electronic data handling functions are accomplished by using interface electronics modules and a data bus to interface the DMS with the pallet-mounted instruments and subsystems.

All scientific telescopes except the infrared telescope provide hard copy (film) outputs using film cannister storage during the seven-day mission. Telescope support equipment, the high-energy arrays, and the pallet-mounted subsystems generate relatively low bit rate data and are accommodated by the Sortie Lab data recorders. The data summaries shown in Table 7 define onboard storage requirements, maximum data rates, and telemetry requirements for each payload grouping.

Table 7 Digital Data Requirements

Baseline Payload		Maximum Data Rate, kbps	On-Board Storage, 10^9 bits	Telemeter - during Mission, 10^6 bits
Solar 1-2		4.0	1.76	743
Stratoscope III Payloads	3AB	4.2	2.04	210
	3AC	8.3	4.30	235
	3AD	4.4	2.20	225
	3AE	8.6	4.43	251
IR Payloads	4AB	4.5	2.00	157
	4AC	8.6	4.30	181
	4AD	4.8	2.15	172
	4AE	8.9	4.43	198

The management of the commands and controls to the pallet and the storage and monitoring of scientific and engineering data from the pallet are accomplished using the data handling components shown in Fig. 14. The digital data bus provides control signals to each instrument and subsystem. Scientific, status, and operational data are returned to the Sortie Lab DMS using the same bus. A central multiplexer on the pallet accommodates signals to and from the forward payload and gimbal, aft payload and gimbal, and support subsystem components. The data bus inteface unit for each payload or subsystem is the direct interface providing decoded commands to the instruments, to the load center switches, or to the support subsystems. Analog outputs from the payload field monitors are directed to the Sortie Lab through video amplifiers located on the pallet junction box.

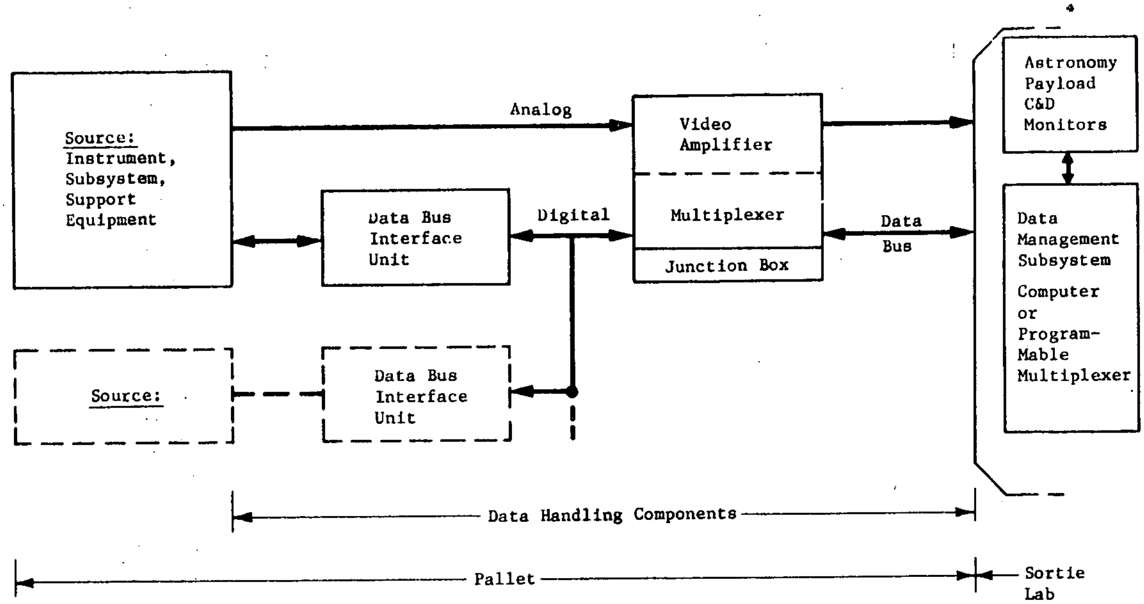


Fig. 14 Data Handling Interface Concept

6. Electrical Power

Electrical power requirements for the baseline mission payloads include the average power for the individual experiments, payload C&D, pallet-mounted support subsystems, and for support equipment such as correlation trackers, bore sight trackers, fine sun sensors, and the field monitoring vidicons. Average power required for the individual mission payloads is shown in Table 8. Power is provided by the Sortie Lab to a central power distribution box mounted on the pallet. Each payload and support equipment is connected to the master junction box through a dedicated load center switch. Power is provided through a relay network to the payload or support subsystem under control of the data bus interface unit located near the payload or subsystem. A fail-safe circuit and relay driver are included in each switch.

Table 8 Mission Payload Power Requirements

Payload	Average Power, W
Solar Payload 1-2	1480
Stratoscope III Payloads	
Payload 3AB	1352
Payload 3AC	1280
Payload 3AD	1383
Payload 3AE	1444
IR Telescope Payloads	
Payload 4AB	1217
Payload 4AC	1145
Payload 4AD	1248
Payload 4AE	1309

E. INTERFACES

The study results presented in this report are very dependent on the interfaces that were used for the Space Shuttle Sortie Lab and pallet. This section summarizes the interface capabilities and constraints used in performing the study analyses.

1. Space Shuttle Interfaces

Interfaces between the Astronomy Sortie mission payloads and the Shuttle are those involving orbital parameters (such as payload capability, orbit inclination, orbit altitude, and vehicle attitude and stability), payload bay environment (such as acoustics and thermal), and physical constraints such as payload center of gravity, size, and shape.

a. *Payload Capability* - The ground rule for this study was that the payload weight could not exceed 80% of the Shuttle capability. The mission analyses performed during the study established the orbital parameters for the baseline Astronomy Sortie missions as:

Solar Payload

- Inclination - 1.38 to 1.57 radians (79 to 90 deg)
- Altitude - 470 to 418 km (254 to 226 n mi)
- Time of Year - February 20 to April 19 and August 25 to October 25

Stellar Payloads

- Inclination - 0.5 to 1.57 radians (28.5 to 90 deg)
- Altitude - 463 to 370 km (250 to 200 n mi)
- Time of Year - Anytime.

Figure 15 shows the Shuttle payload capability as a function of altitude and inclination for 80% of the baseline capability. This figure assumes that the air breathing engine system (ABES) is not installed on the Orbiter. Also shown on the figure are the estimated weights for the nine sortie mission payloads. In each case, a Sortie Lab weight of 5760 kg (12,688 lb) and a pallet weight of 1390 kg (3060 lb) was used.

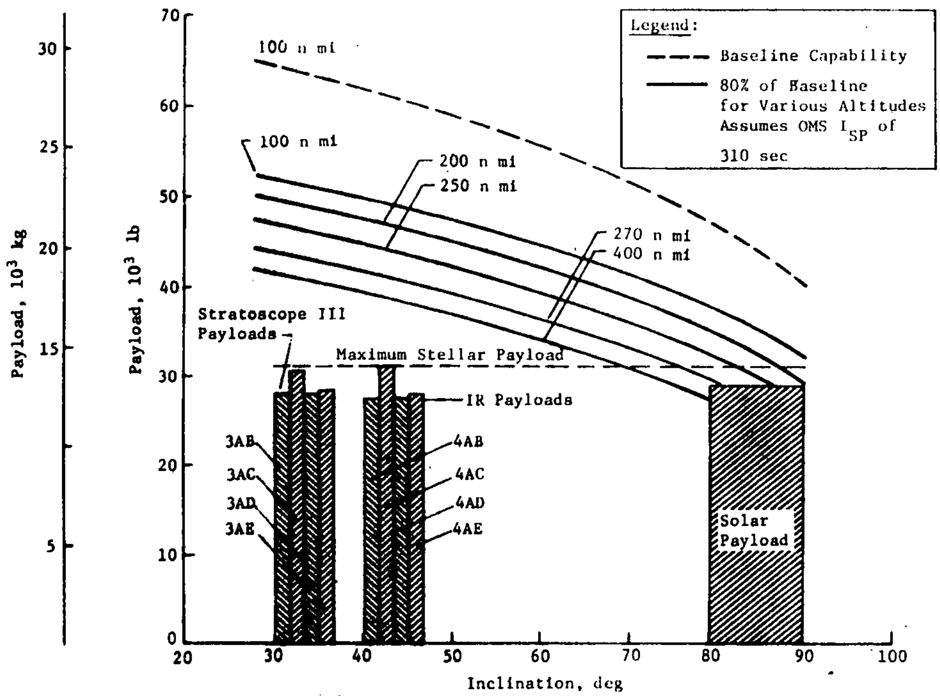


Fig. 15 Shuttle Payload Capability

b. Operational Constraints - The following operational constraints were assumed or derived during the study:

Attitude Constraint - There were no attitude constraints on the Shuttle and an X-POP inertial attitude could be maintained for the seven-day sortie mission.

Air Breathing Engines - ABES was not required for the Astronomy Sortie missions.

Launch Time - A 24-hr launch capability.

Space Shuttle Stabilization - Three CMGs are recommended to stabilize the Shuttle in an X-POP inertial attitude.

Orbit Inclination - To satisfy the experiment objectives, orbit inclinations from 0.5 to 1.57 radians (28.5 to 90 deg) are required.

c. Acoustic Levels - The acoustic spectrum and OASPL used as a baseline for this study are presented in the top curve of Fig. 16. These data were extracted from the document *Payload Design Requirements for Shuttle/Payload Interface* (Ref 12). The OASPL should not exceed approximately 140 dB for the astronomy experiments. The lower curve in Fig. 16 shows the expected acoustic spectrum and OASPL, based on the results of Titan III test data, for the addition of 9.76 kg/m^2 (2.0 lb/ft^2) of acoustic material. As shown on the figure the OASPL is down to 140 dB with this protection. Calculated wall densitities for the telescopes are:

Photoheliograph - 18.6 kg/m^2 (3.83 lb/ft^2)

Stratoscope III - 26.1 kg/m^2 (5.35 lb/ft^2)

IR Telescope - 66.3 kg/m^2 (13.6 lb/ft^2)

Container for other solar telescopes - 9.77 kg/m^2 (2.04 lb/ft^2).

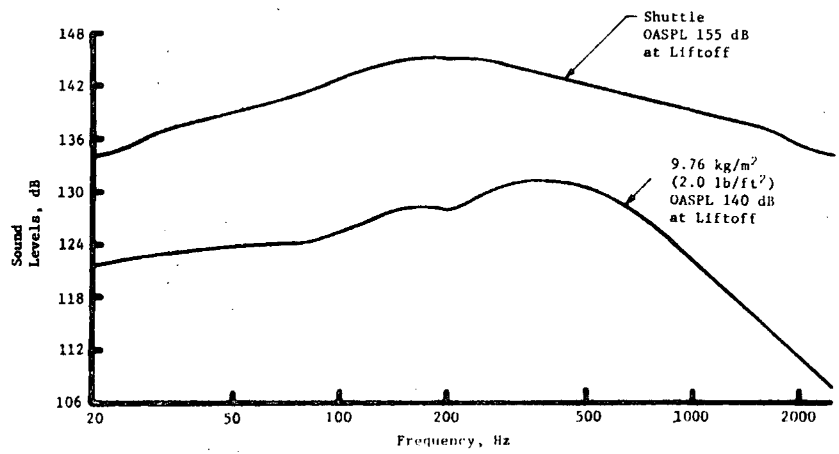


Fig. 16 Shuttle Cargo Bay Acoustic Environment

In addition, the Space Shuttle RFP specifies an OASPL for the cargo bay of 145 dB. This reduction in OASPL in conjunction with the acoustic protection provided by the instruments themselves should minimize the effects of the acoustical environment on the astronomy payloads.

d. Thermal Environment - The Space Shuttle thermal environment used for this study was based on the results of in-house activities. In analyzing the effects on the astronomy payloads during ascent and prior to opening the cargo bay doors, the environment shown in Figure 17 was used. The Shuttle RFP defined a thermal environment (Table 9) that was not as severe as the one used during this study.

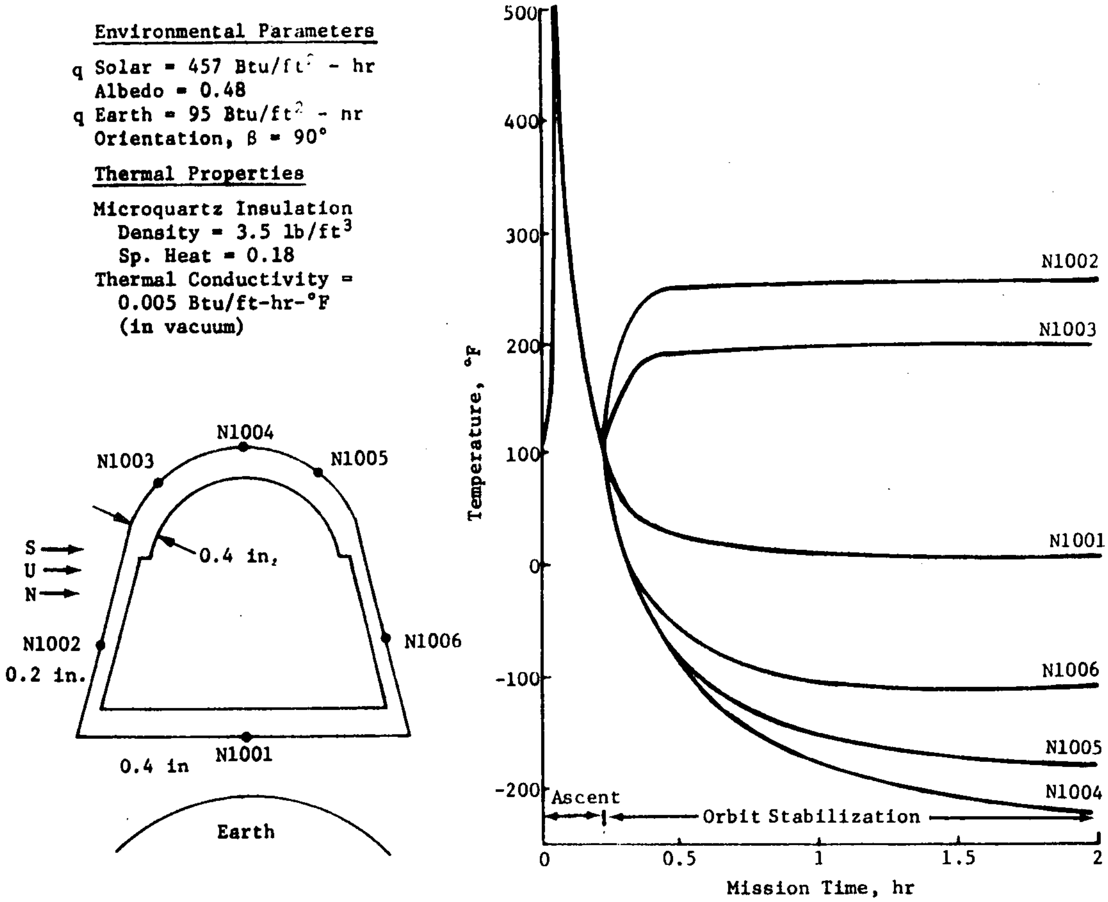


Fig. 17 Shuttle Thermal Environment

Table 9 Payload Bay Wall Thermal Environment (Adiabatic Payload Bay Wall)

Condition	Minimum, °F	Maximum, °F
Prelaunch	+40	+120
Launch	+40	+150
On-Orbit (door closed)	-100	+150
On-Orbit (door open)	--	--
Entry and Postlanding	-100	+200

The results of the thermal analysis for the ascent phase of the mission indicated that the Shuttle thermal environment has little effect on the internal temperatures of telescopes that have insulation blankets equivalent to the MDA on Skylab.

During the on-orbit phase of the mission, the Grumman Shuttle Orbiter configuration and characteristics were used in the thermal analysis. Table 10 identifies the orbital and environmental conditions that were used in the detailed analysis of the IR telescope.

Table 10 Orbital and Environmental Conditions

Orbital Conditions	
Orbit Altitude	235 n mi
Beta Angle	90 deg
Orientation	Solar Oriented
Environmental Conditions	
Solar Constant	458 Btu/hr-ft^2
Albedo	0.4
Planetary Emission	78 Btu/hr-ft^2
Surface Coating Properties, α/ε	
Orbit	0.9/0.9
Orbiter Radiator	0.1/0.9
Pallet/Payload	0.2/0.9

Table 4 showed the absorbed flux, equivalent space sink temperature, and grey body viewfactor to space for the Shuttle configuration and the orbital and environmental conditions specified above. For comparison, the same parameters were shown for a free-flying telescope in the same orbit. The results of the analysis indicated that the Space Shuttle cuts down on the telescope grey body viewfactor to space, and results in a sink temperature that is 29°F warmer than an equivalent free-flying telescope. The absorbed fluxes are averaged around the telescope cylindrical surface for one orbit period.

e. Center of Gravity Constraint - The cg constraints defined by the Shuttle RFP for the payloads within the Shuttle bay are shown in Fig. 18. Current estimates of the astronomy payload weights and cg are also plotted. All payloads are within the constraints.

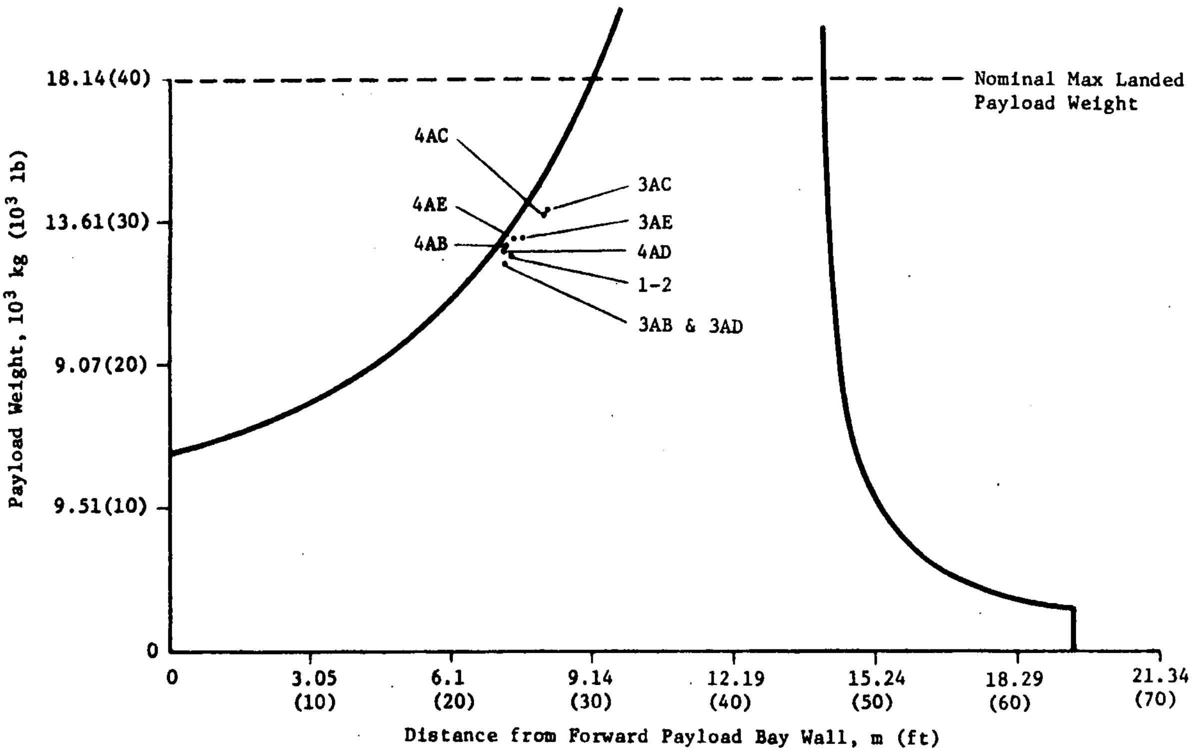


Fig. 18 CG Constraint

f. Shuttle Bay Size - All of the payloads are within a payload bay envelope of 4.57 m (15 ft) diameter and 18.23 m (60 ft) long.

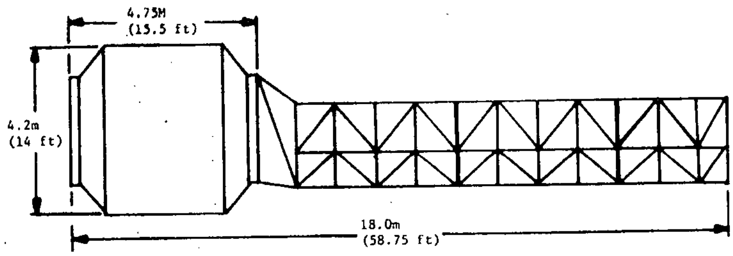
g. Communication - Table 7 summarized the communication requirements for the nine astronomy payloads, which ranged from 157 x 10^6 to 743 x 10^6 bits per mission. These data quantities are the total data that must be transmitted to the ground in real time or near real time during the seven-day mission.

h. Mechanical - Mechanical attachment to the Shuttle will be through the Sortie Lab and pallet. The solar payload requires that the Sortie Lab and pallet be deployed (rotated up 90 deg) from the payload bay by a payload deployment mechanism assumed to be part of Shuttle.

2. <u>Sortie Lab and Pallet Interfaces</u>

Primary interfaces for the Astronomy Sortie mission program are between the experiments with their mount, data, and control systems and the Sortie Lab and pallet. These interfaces are both electrical and mechanical. Design emphasis has been placed on commonality of interfaces for the nine astronomy payloads. This is accomplished by a common modification of the baseline pallet that will then accommodate each of the payloads by a physical interchange of hardware and reprogramming or junction box rewiring of control, data, and power systems.

The Sortie Lab and pallet definition used for this study is summarized in Fig. 19. These data were extracted from the MSFC document *Sortie Can Conceptual Design* (Ref 5).



Sortie Lab Weight	5,760 kg	(12,688 lb)
Pallet Weight	1,390 kg	(3,060 lb)
Total	7,150 kg	(15,748 lb)

<u>Subsystem Support to Experiments</u>

Power	∿ 1.5 kW Avg
EC/LS	∿ Autonomous System - 2 Men for 7 Days
Thermal	∿ 15,000 Btu/hr (Nondeployed); 51,000 Btu/hr (Deployed)
Data	∿ Record at 100 kbps
Comm	∿ Voice & 5 kbps through Shuttle; 10 kbps Uplink (through Shuttle)
C&D	∿ Multifunction Control & Display; Computer Controlled

Fig. 19 Baseline Sortie Lab and Pallet

a. *Quantity of Sortie Labs and Pallets* - To satisfy the maximum baseline flight schedule of eight astronomy sortie missions per year, a total of two Sortie Labs and two pallets are required.

b. *Sortie Lab and Pallet Physical Characteristics* - To provide adequate space to arrange the selected payload groups, a 4.75 m (186 in.) long Sortie Lab and a 13.2 m (519 in.) pallet of which 12.2 m (480 in.) is flat bed structure is required. The pallet floor or plane of azimuth table attachment is 1 m (40 in.) below the centerline of the Shuttle payload bay. Overall length of Sortie Lab and pallet is 18.0 m (705 in.). When the wide coverage X-ray detector is attached, the overall assembly is increased to 18.2 m (715 in.). A 4.27 m (14 ft) diameter Sortie Lab was used for this study, however, larger diameters within the maximum limit of the payload bay would not interfere with instrument viewing. In calculating the mass properties of the astronomy payloads, the cg assumed for the Sortie Lab and Pallet were 2.29 m (90 in.) and 11.3 m (444 in.) from the forward end of the Shuttle cargo bay, respectively.

c. Mechanical Interface - There are two types of mechanical interfaces to the pallet: (1) those structural attachments that are major load-carrying interfaces and/or require a high degree of alignment; and (2) equipment supports.

Major structural attachments are required for three control moment gyros; a pallet inertial measurement unit; two azimuth tables; four deployment locks; and two wide coverage X-ray detector mounts. Equipment supports are required for a control input box; three CMG inverters; an ordnance package; an interface junction box; cabling; and three cable cutters. The mechanical interfaces to the Sortie Lab are the umbilical plate and the structural attachment for the experiment control and display console.

d. Power Interface - The electrical power interface between the ASM cabling system and the Sortie Lab will be at the interface junction box. The average power requirements for the payloads range from 1145 to 1480 W. This power is the average power required by the experiments and experiment support equipment, including the control and display console in the Sortie Lab.

e. Data Interface - Experiment data output consists of film and digital format. The film remains in the instrument for the duration of the mission. Digital data are transferred to the Sortie Lab on coax cables. Table 7 summarizes the digital data and shows the maximum data rate transferred to the Sortie Lab, the data storage required during the seven-day sortie mission, and the data that must be transmitted to the ground in real time or near-real time.

The data system defined for the Astronomy Sortie missions uses the Sortie Lab data management system for all computational requirements, storage requirements, formatting, etc.

f. Control and Display - The C&D concept identified for the Astronomy Sortie missions is a separate C&D console that interfaces with the Sortie Lab C&D and data management systems. The Astronomy Sortie C&D does require hardwire interconnections to the experiments on the pallet. These hardwire connections will provide for the experiment-peculiar analog signals, video monitors, and caution and warning circuits.

g. Thermal - The astronomy equipment on the pallet will not require a fluid interface. Thermal control will be provided by electrical energy or it will be incorporated into the telescope designs. The C&D console in the Sortie Lab will require cold plates for the dissipation of approximately 400 W of electrical power.

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VI. STUDY LIMITATIONS

The purpose of this study was to provide NASA with an overview of the Astronomy Sortie mission program requirements. It was necessary to restrict the study to a specific set of experiments, and a specific set of guidelines, constraints, and assumptions to ensure that the study was performed on schedule and within the funding constraints. The recommendations and conclusions that are made are very dependent on the limits placed on the study. Several of the more significant limitations are discussed in this chapter.

Baseline Experiment Definition - The experiments baselined for the study were representative experiments only. Many of the interface support hardware, support personnel, facility, GSE, and mission requirements defined in this report would change depending on the specific set of experiments considered. In general, the major changes would be in the quantities of the requirements rather than the type of requirement.

Baseline Flight Schedule - The flight schedule baselined for the study consisted of two to eight Astronomy Sortie missions per year. Each stellar Astronomy Sortie mission consisted of one stellar telescope and a group of high-energy arrays. The solar payload consisted of two groups of solar telescopes. The quantities of resources, facilities, personnel, Sortie Labs, pallets, GSE, logistics, etc, were all predicted on this baseline flight schedule and could change drastically depending on the frequency of the Astronomy Sortie missions.

Space Shuttle Sortie Mission Mode of Operation - The mode of operation baselined for the study consisted of: (1) a Sortie mission of seven-days duration; (2) a maximum of two experiment crewmen; and (3) 24-hr/day for experiment operation. Each of these operational considerations had an impact on the study results. The mission duration affects such items as the type of data recording (i.e., film or electronic imaging), the mission profile (altitude and inclination required for continuous sun), the type and quantity of expendables (open-loop vs closed-loop cryogenic systems), payload weights (additional expendables required for power, cryogenic, etc), and the mission effectiveness. The size of the experiment crew and the 24-hr/day experiment operation determined the size of the Sortie Lab, the amount of consumables, the operating efficiency, and the crew activities.

Space Shuttle Capabilities and Constraints - The Astronomy Sortie mission program defined in this study was based on the current data available on the operational Space Shuttle. As the Space Shuttle work progresses, it can be expected that changes will be made in the Shuttle environments, interface capabilities, operational constraints, physical configuration, etc. The results of this study were very dependent on the Shuttle capabilities and constraints and would change as the Shuttle definition changes.

Sortie Lab and Pallet Capabilities and Constraints - The on-orbit support hardware required for Astronomy Sortie missions and the interface requirements on the Sortie Lab and pallet were based on the capabilities and constraints identified in the NASA/MSFC document entitled, *Sortie Can Conceptual Design* (Ref 5). As work continues on the Sortie Lab and pallet it can be expected that changes will occur that will effect the results of this study.

VII. IMPLICATIONS FOR RESEARCH

The Astronomy Sortie mission concept defined in this report is within the present day state of the art with the exception of: (1) telescope fine stabilization actuators; (2) precision star trackers; and (3) contamination control and countermeasures. The supporting research and technology (SRT) required for these items is summarized below.

The telescopes designated as candidates for the Sortie mission would require some SRT, but detailed definitions have not been made, because these will be covered by the contractors performing the definition studies. Typical of the SRT items required for the telescopes are: (1) an aspheric grating for the XUV spectroheliograph; (2) IR detectors for the cooled IR telescope; (3) cryogenic systems for the IR telescope, requiring 30°K, and and for the IR detectors, which will be cooled to approximately 2°K; and (4) systems for controlling contamination of critical surfaces of telescopes.

A. TELESCOPE FINE STABILIZATION ACTUATORS

The state of the art for stabilizing telescopes attached to manned spacecraft is Skylab. The projected stabilization capability of this Skylab system as determined by computer simulation is 10 μrad (2 $\widehat{\text{sec}}$) in azimuth and elevation.

The ASM telescope gimbal assembly stabilization goal of 0.5 μrad (0.1 $\widehat{\text{sec}}$) is 20 times better than that of Skylab. Even this stringent ASM stability goal is not sufficient for the photoheliograph and Stratoscope III, and these two telescopes will augment the telescope gimbal assembly using internal image motion compensation to meet their final required stability. The baseline stability goal of 0.5 μrad (0.1 $\widehat{\text{sec}}$) is beyond that of the present verified state of the art and a system to provide this capability should be developed.

B. PRECISION STAR TRACKER

In proper guidance of the high resolution ASM telescopes, an absolute angular measurement (pointing) accuracy of ± 5 μrad (± 1 $\widehat{\text{sec}}$) and an angle resolution (stability) of 0.5 μrad (0.1 $\widehat{\text{sec}}$) is required. These are considered design goals for the stabilization and control system.

Precision star trackers capable of providing these requirements (when operated with appropriate actuators) have not been developed. Current state of the art equipment achieves about ± 25 μrad (± 5 $\widehat{\text{sec}}$) absolute angle measurement accuracy with resolution of 10 μrad (2 $\widehat{\text{sec}}$). A precision star tracker will have to be developed to satisfy the pointing and stability requirements of the Astronomy Sortie mission concept.

C. CONTAMINATION CONTROL AND COUNTERMEASURES

During the missions, the Orbiter and Sortie Lab are expected to be significant sources of contaminants. The nature and rates of deposit of detrimental contamination from these sources have not been defined. Equipment to reduce or eliminate "harmful" contaminants or countermeasures to dispense or prevent their deposition may be necessary.

VIII. SUGGESTED ADDITIONAL EFFORT

The results of this study give NASA an overview of the Astronomy Sortie mission program requirements for a specific set of experiments, guidelines, and assumptions. Modifications to the baseline condition or assumptions could have a significant impact on the results of this study. To provide a broader base for NASA planning purposes, it is suggested that the following additional effort should be performed before deciding on a recommended Astronomy Sortie mission program.

Astronomy Sortie Mission Continuation Study - The present study, or one very similar, should be continued to ensure the compatibility between the Astronomy Sortie missions concept and (1) the Astronomy Sortie mission objectives and instrument requirements currently being defined; (2) the Space Shuttle definition; (3) the Sortie Lab and pallet definition; and (4) the establishment of the operational Space Shuttle management and operation philosophies. The purpose of this continuation study would be to: Track the results of related NASA efforts; determine their impact on the established Sortie mission concept; ensure that the related efforts are cognizant of the Astronomy Sortie mission requirements; and translate the above tasks into requirements that can be reflected in NASA planning activities.

Detector Access - A controversial area that surfaced during the present study was the desirability of the scientific community to have on-orbit shirtsleeve access to the focal plane of the telescopes. The concept defined for the Astronomy Sortie missions in this study does not provide this capability because the entire telescope is located external to the Sortie Lab pressure shell. It is suggested that a separate study be dedicated to the cause and effect of on-orbit access to the detectors. The study should consider the scientific objectives that require the on-orbit access, and then proceed through two conceptual designs that satisfy these scientific objectives. One design would provide for on-orbit shirtsleeve access to the detectors, while the other would require all operations to be by remote control. Based on the cursory look given this issue in the present study, the conceptual designs and the interface definitions between the Astronomy Sortie mission program and the Space Shuttle, Sortie Lab and pallet, and experiment definitions would be very divergent for the two alternatives identified. If this controversy is not settled early in the Astronomy Sortie mission program definition phase, major complications could arise in future activities.

Extended Sortie Mission Capabilities - The Sortie mission mode of operation considered in this study was a seven-day mission with a maximum of two experiment crewmen. The effect of extended the Sortie mission duration to 14 or 30 days or increasing the crew size should be evaluated because this could change some of the recommendations made in this study. Several of the more important considerations that should be evaluated are (1) the size of the Sortie Lab; (2) amount of consumables including film and cryogenics; (3) use of open-loop vs closed-loop cryogenic systems for longer duration missions; (4) radiation effects on film; (5) Shuttle stabilization system for longer missions; (6) number of experiments contained in a payload for increased crew size; (7) size of control and display console; (8) reduced payload weight due to increased consumables and crew; (9) operating efficiency; and (10) reliability and maintainability. The above parameters are not inclusive, but they do indicate the sensitivity of the Astronomy Sortie program to the mission duration and crew size and strongly suggest that the extended mission capabilities should be evaluated.

Film vs Electronic Imaging - During the telescope definition tasks of this study it was recommended that film be used for the Astronomy Sortie missions because high resolution film is state of the art and provides a very high density storage medium. This recommendation was based on a seven-day mission duration and the desire to limit the communication requirements. It is suggested that a separate study be performed on the use of film versus electronic imaging for the Astronomy Sortie missions. The study should consider the following items: (1) telescope and instrument design and performance; (2) state of the art; (3) Sortie Lab data handling requirements; (4) crew activities; (5) Space Shuttle communication requirements; (6) ground data reduction and processing requirements; and (7) ground data storage and cataloging requirements. The results of this study would have major implications on the overall Astronomy Sortie program.

The above studies suggested for additional effort could have a significant influence on the overall Astronomy Sortie program. In addition to these general studies, several technology-type studies should be initiated. A simulation of the recommended telescope fine pointing and stabilization system should be performed to verify the feasibility of such a system. Also, the control moment gyro (CMG) system recommended as the stabilization system for the Space Shuttle should be studied in more detail to determine if the contamination that would be present with a propulsive stabilization system would be prohibitive to the astronomy operation.

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